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ISSUE 124

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If you've always wanted to know everything there is to know about Mars, then you'll love our cover feature – it's a complete guide to the Red Planet, revealing missions that have visited its surface or will do in the future, its moons, what's on its surface and all other facts and pieces of information in between. Turn to page 14; I can guarantee you'll discover something you didn't know about the fourth world from the Sun.

Also this issue, we uncover that the ice giants – Neptune and Uranus – are even weirder than astronomers thought. They've been discovered to be leaking gas into space, leaving them with less ammonia in their atmospheres than expected. Grappling with the latest data, though, researchers at the Université Côte d'Azur in Nice, France, feel that they've hit upon the reason why: mushballs. It could take many years to know for sure, but the study into the most misunderstood worlds in the Solar System is enlightening.

Last month, I promised a beginner's guide to astrophotography. I'm pleased to say that astrophotographer Stuart Cornell has revealed the very best tips and tricks to get you started – along with the very best targets to begin shooting this month. Don't forget to send your images to us; we'd love to see them!

GEMMA LAVENDER
CONTENT DIRECTOR

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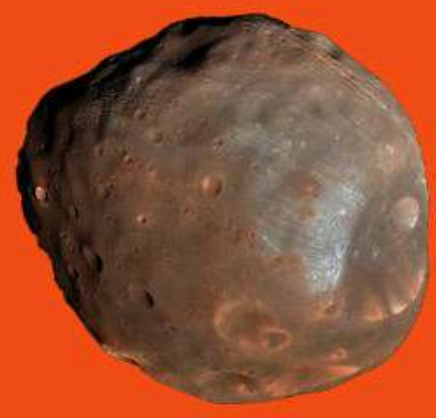

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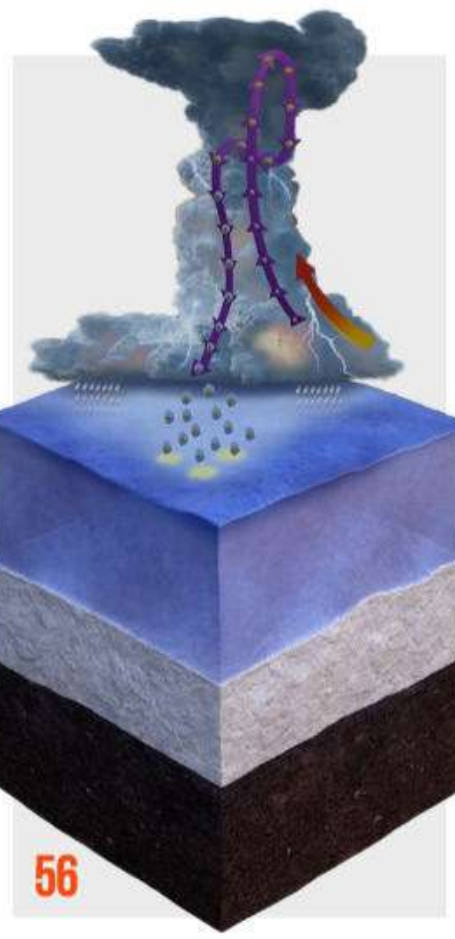

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A second look

Around 180 million light years away in the constellation of Indus lies NGC 6984, a spiral galaxy with dark lanes of gas and dust. Its star-studded arms are brimming with bright star-forming regions. This stunning image was captured by the Hubble Space Telescope's Wide Field Camera 3, but it's not the first time Hubble has taken its picture; the galaxy was also imaged in 2013. By combining the 2013 observations with the new data, a more detailed image with a greater range of colours has been created.

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LAUNCH PAD

YOUR FIRST CONTACT WITH THE UNIVERSE

19 OCTOBER 2021

Mars' icy past revealed

The Mars Reconnaissance Orbiter has captured an image revealing Mars' icy past. These U-shaped ridges along a crater wall are indicative of glacial movement. The scalloped ridges contain rocks that were collected by a glacier as it moved downslope, forming moraines – a collection of debris formed by glacial movement. Though the ice is no longer present, the evidence of glacial movement in these moraines informs scientists about the existence of past Martian glaciers and shows how influential they were in creating the Martian landscape we see today.

© NASA/JPL-Caltech/University of Arizona

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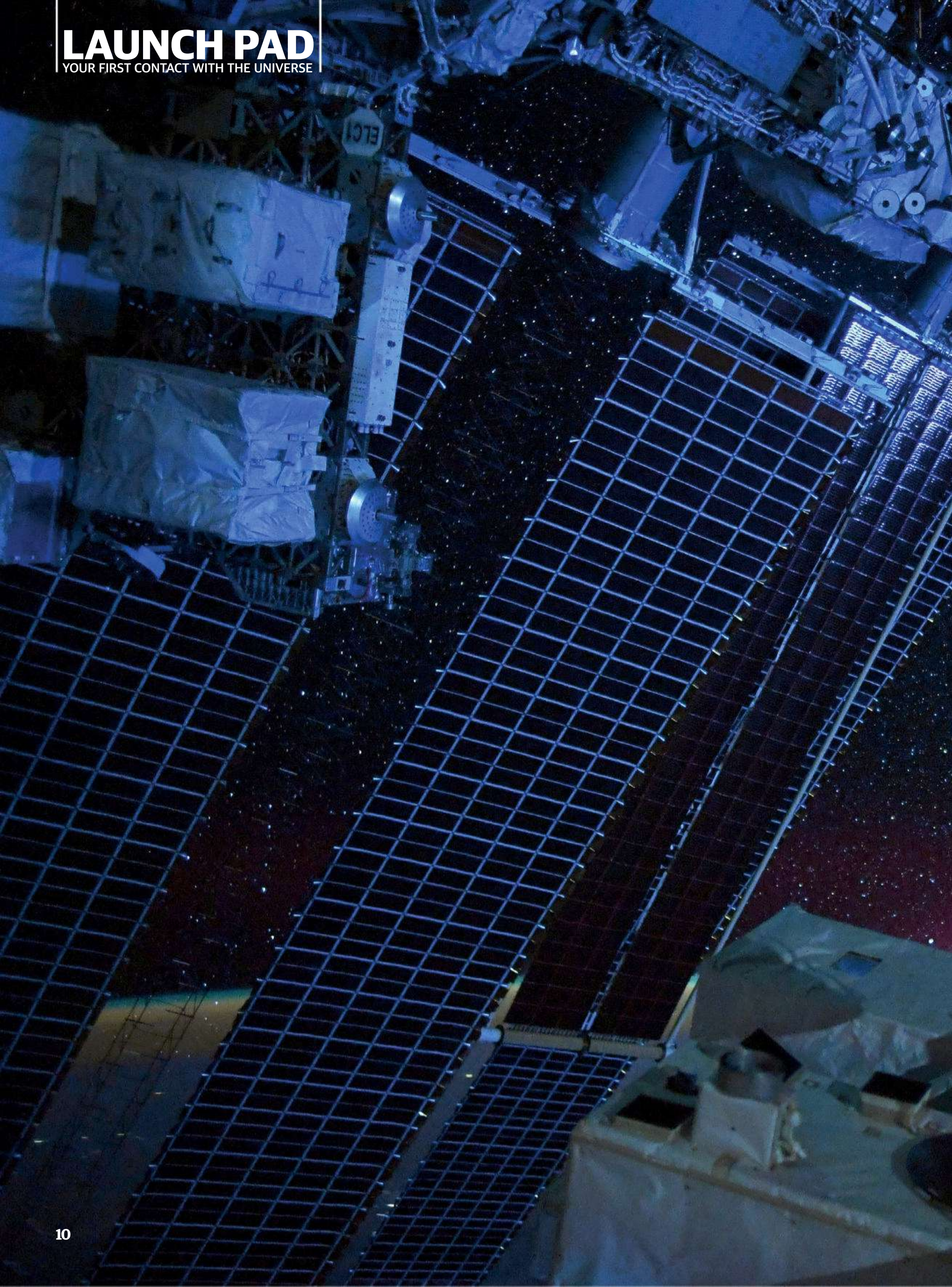

4 NOVEMBER 2021

A stellar view

European Space Agency astronaut Thomas Pesquet captured this exquisite image awash with a starry backdrop while on board the International Space Station (ISS). There are plenty of impressive photos taken by astronauts on the ISS, but while most point down towards Earth, this one from Pesquet looks up to the stars instead. According to Pesquet: "When you let your eyes adapt to the night, you start seeing millions of stars and it's amazing... there's also a lot of beauty in the cosmos itself, it's just harder to see at first."

© ESA/NASA

Below: Analysing exoplanets to determine habitability is a big focus

HABITABLE EXOPLANETS, BLACK HOLES AND INCLUSIVITY ARE TOP PRIORITIES FOR THE NEXT DECADE

Words by Mike Wall

On 4 November, the US National Academies of Sciences, Engineering and Medicine released a decadal survey laying out scientific priorities and funding recommendations for the next ten years. The document, called *Pathways to Discovery in Astronomy and Astrophysics for the 2020s*, identifies three top-line items the disciplines should concentrate on: the discovery and study of habitable exoplanets, the exploration of black holes and neutron stars as windows to the early universe and a better understanding of the origin and evolution of galaxies. It also stresses the importance of making astronomy a more inclusive and diverse field. A lot of work goes into these documents, which are drawn up by prominent researchers in the fields that they cover. The survey identifies three 'priority areas' that should receive special attention and investment over the next decade.

One, called 'Pathways to Habitable Worlds', is a program designed to help discover and characterise Earth-like exoplanets, with the goal of eventually capturing photos of such worlds and analysing their atmospheric composition. The second, 'New Windows on the Dynamic Universe', describes an intensified effort to study black holes and neutron stars with a diversity of instruments on the ground and in space, including gear that detects gravitational waves. Gaining a better understanding of these exotic, superdense objects could shed light on the very early universe. The third focus area, 'Unveiling the Drivers of Galaxy Growth', aims to revolutionise our understanding of galaxy formation and evolution, "from the nature of the tenuous cosmic webs of gas that feed them to the nature of how this gas condenses and drives the formation of stars".

The survey recommends the establishment of a 'Great Observatories Mission and Technology Maturation Program' – a callback to NASA's Great Observatories program, which launched four powerful space telescopes from 1990 to 2003, starting with the iconic Hubble Space Telescope. The survey also recommends that this program's first mission should be an infrared/optical/ultraviolet (IR/O/UV) space telescope with a primary mirror about six metres (19.7 feet) across. That's about 2.5 times wider than Hubble's mirror and roughly the same size as that of the James Webb Space Telescope, which is optimised to view the cosmos in infrared.

This envisioned space telescope could search for biosignatures in the atmospheres of about 25 potentially habitable exoplanets and be ready for launch in the early 2040s. And its mission could be mounted for about $11 billion (£8.2 billion), if all goes well.

The decadal survey also recommends making key investments in huge ground-based telescopes – especially the Giant Magellan Telescope, currently being built in the Chilean Andes, and the Thirty Meter Telescope, which is slated to be constructed in Hawaii, but has met with opposition in the state.

The decadal also stresses that more investment is needed to support research facilities, early career scientists and important activities such as data archiving. Both astronomy and astrophysics are male-dominated fields, with the representation of minoritised groups lower than that of society at large – a situation that the new report would like to help change. "Funding to support diverse faculty in university astronomy and astrophysics programs should be increased," the survey states.

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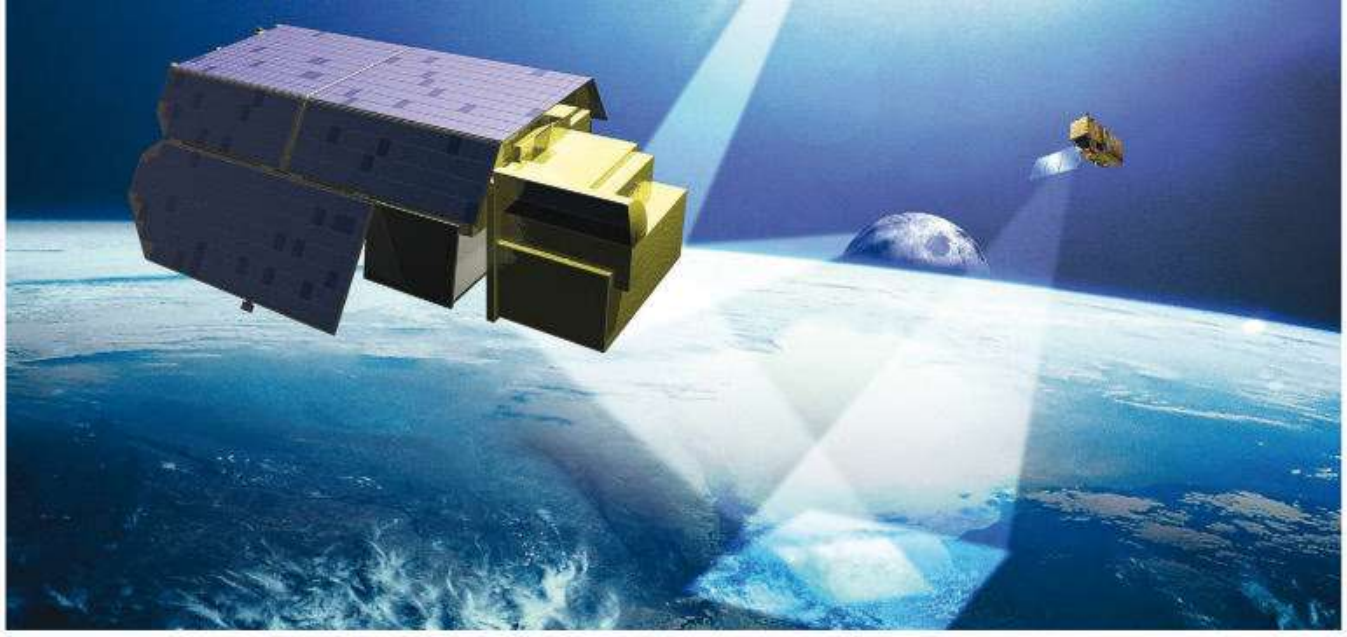

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Above: The new mission will monitor how much energy our planet reflects

NEW MISSION WILL MEASURE HOW MUCH HEAT EARTH IS TRAPPING FROM CLIMATE CHANGE

Words by Tereza Pultarova

A new space mission will measure how much heat gets trapped in Earth's atmosphere to help gauge whether humanity is making any progress in tackling the worst effects of climate change. The mission, called TRUTHS – for Traceable Radiometry Underpinning Terrestrial- and Helio- Studies – is currently being prepared by the European Space Agency (ESA) and its partners. It will study the so-called Earth energy balance – the difference between how much energy arrives at the planet from the Sun and how much gets reflected back into space. The more heat Earth keeps, the warmer it gets, and it's dangerous greenhouse gases that create conditions for the planet to trap more of the incoming heat.

TRUTHS, introduced at the UN Climate Change Conference (COP26) in Glasgow, Scotland, on 3 November, will "set a benchmark to detect changes in Earth's climate system," said the ESA. The spacecraft will carry two main instruments: the Cryogenic Solar Absolute Radiometer and the Hyperspectral Imaging Spectrometer. These two instruments will continuously measure incoming and reflected solar radiation. The mission will help detect changes in Earth's climate faster, but will also create a super-accurate reference system that will be used as a benchmark for other measurements and climate models. The mission is still awaiting a decision on funding, but if all goes well, it should be in orbit by 2029.

ASTRONOMERS DETECT WATER IN ONE OF THE OLDEST KNOWN GALAXIES

Words by Tereza Pultarova

Astronomers have detected traces of water in one of the oldest known galaxies, proving for the first time that the life-giving substance played a role in the formation of the earliest stars. The galaxy, called SPT0311-58, is located some 12.88 billion light years from Earth, meaning that our telescopes see it as it looked only 1 billion years after the Big Bang. Astronomers estimate that the galaxy is only 780 million years old, an age at which stars formed at a much higher rate than they do in more mature galaxies.

The observation, the most distant detection of water in the universe, was made by the Atacama Large Millimeter/submillimeter Array (ALMA), a powerful radio telescope in northern Chile in the Atacama Desert. In addition to water, ALMA also detected carbon monoxide. SPT0311-58, discovered by ALMA in 2017, is the most massive currently known galaxy of this ancient age, and actually consists of two galaxies that appear to be merging. It has more gas and dust compared to galaxies at closer distances, which are more mature.

Astronomers currently don't understand how such huge amounts of gas and dust assembled in the young universe to form the first stars and early galaxies. But they do know that stars in young galaxies form at a thousand times greater rate than in the Milky Way. Water is the third most common molecule in the universe after hydrogen and carbon monoxide, and some studies suggest that it might be used as a signature of star formation.

Below: The merging galaxies formed near the universe's beginning

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A MASSIVE COMET EXPLODING OVER CHILE 12,000 YEARS AGO MAY HAVE CREATED STRANGE GLASSY ROCKS

Words by Meghan Bartels

A 75-kilometre (47-mile) swath of desert is strewn with strange, dark, glassy rocks that have long puzzled scientists. New research finds that those rocks are quite similar to comet particles collected by a NASA mission called Stardust. The scientists behind the work think that all those years ago, one or more huge comets exploded together in the skies over the region, causing tornado-force winds, scorching the grassy landscape and scattering the area with warped and twisted glass that still contains minerals generally found only in meteorites. "This is the first time we have clear evidence of glasses on Earth that were created by the thermal radiation and winds from a fireball exploding just above the surface," said Pete Schultz, a geologist at Brown University.

Schultz and his colleagues collected 300 pieces of the strange glassy rock to analyse from two patches of the region. In addition, the team cut thin, polished slices out of 20 of those samples to study under a microscope. In all of those slices, the researchers found dozens of grains and fragments that didn't match the region.

Those anomalies include a mineral called troilite, which is typically found in meteorites, and decomposed zircons, suggesting that the samples reached temperatures hotter than 1,670 degrees Celsius (3,000 degrees Fahrenheit). Scientists can't yet precisely date the glassy rocks, although other research on the phenomenon has suggested the strange rocks formed between 12,300 and 11,500 years ago.

Above: A meteor might solve the mystery of strange rocks

WEIRD COSMIC OBJECT KEEPS EXPLODING OVER AND OVER, AND SCIENTISTS DON'T KNOW WHY

Words by Adam Mann

A mysterious object has shot out 1,652 blasts of energy over a short period. Though researchers are still stumped as to what caused the repeated eruptions, they hope their observations will help them get closer to an answer. The entity is a fast radio burst (FRB), an enigmatic phenomenon first observed in 2007. FRBs produce pulses in the radio part of the electromagnetic spectrum; these pulses last only a few thousandths of a second, but produce as much energy as the Sun does in a year.

© Getty

Some FRBs emit energy just once, but several – including an object called FRB 121102, located in a dwarf galaxy 3 billion light years away – are known to repeat their bursts. Using the Five-hundred-meter Aperture Spherical Telescope (FAST) in China, scientists decided to conduct an extensive study of this repeating FRB. Over about 60 hours, the researchers watched FRB 121102 explode 1,652 times – sometimes up to 117 times per hour, far more than any previously known repeating FRB.

Most FRBs occur in the distant universe, which makes them difficult to study. But in 2020, astronomers found an FRB inside our Milky Way, allowing them to determine that the source was a type of dead star called a magnetar. Whether all FRBs are magnetars has yet to be determined. If FRB 121102 is indeed a magnetar, the data collected on it suggests that the quick explosive bursts are happening right on the surface of the star itself, and not in the surrounding gas and dust.

Left: FRB 121102 is the most active of its kind

Right: The mission is vital for long-term human missions of the future

IN COOPERATION WITH SPACE.com

NASA PICKS LANDING SITE AT THE MOON'S SOUTH POLE FOR ICE-DRILLING ROBOT

Words by Elizabeth Howell

NASA has set its sights on the Moon's south pole in its quest for ice. The space agency and company Intuitive Machines have announced a Shackleton crater landing site at the lunar south pole for a small lander set to launch next year. The location is called the 'Shackleton connecting ridge'. The mission includes NASA's Polar Resources Ice Mining Experiment-1 (PRIME-1), requiring solar power and a view of Earth for communications.

NASA frames PRIME-1 as a key step in learning how to mine resources from the lunar surface. The agency plans to land a series of longer human missions on the Moon, known as Artemis, later in the 2020s. But to make such an effort sustainable, scientists and engineers need to practice in-situ resource utilisation, which is the practice of using resources in the local environment – in this case mining the Moon.

PRIME-1 aims to deploy a drill, called The Regolith Ice Drill for Exploring New Terrain (TRIDENT), which will attempt to burrow as deep as almost one metre (three feet) underneath the lunar surface.

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A: Orion (the Hunter) **B:** Musca (the Fly) **C:** Taurus (the Bull)

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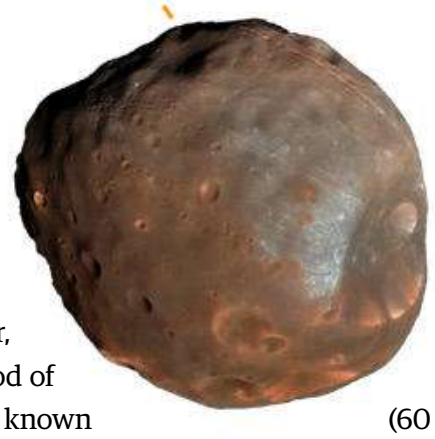
THE COMPLETE GUIDE

MARS

WE'RE LEARNING MORE ABOUT THE FOURTH ROCK FROM THE SUN EVERY DAY

Reported by Charles Q. Choi & Robert Lea



Mars is the fourth planet from the Sun. Befitting the Red Planet's bloody colour, the Romans named it after their god of war. The bright rust colour Mars is known for is due to iron-rich minerals in its regolith – the loose dust and rock covering its surface. The soil of Earth is a kind of regolith, too, albeit one loaded with organic content. The iron minerals on Mars oxidise, or rust, causing its soil to look red.

The planet's thin atmosphere means liquid water likely cannot exist on the Martian surface for any appreciable length of time. Features called recurring slope lineae may have spurts of briny water flowing onto the surface, but this evidence is disputed; some scientists argue the hydrogen spotted from orbit in this region may instead indicate briny salts. This means that although this desert planet is just half the diameter of Earth, it has the same amount of dry land.

The Red Planet is home to both the highest mountain and the deepest, longest valley in the Solar System. Olympus Mons is roughly 25 kilometres (16 miles) high, about three times as tall as Mount Everest, while the Valles Marineris system of valleys – named after the Mariner 9 probe that discovered it in 1971 – reaches as deep as ten kilometres (six miles) and runs east to west for roughly 4,000 kilometres (2,500 miles), about one-fifth the distance around Mars and close to the width of Australia.

Scientists think that Valles Marineris formed mostly by rifting of the crust as it got stretched. Individual canyons within the system are up to 100 kilometres (60 miles) wide. The canyons merge in the central part of Valles Marineris in a region 600 kilometres (370 miles) wide. Large channels emerging from the ends of some canyons and layered sediments within suggest that the canyons might once have been filled with liquid water. Mars also has the largest volcanoes in the Solar System – Olympus Mons being one of them. The massive volcano, which is about 600 kilometres (370 miles) in diameter, is wide enough to cover the state of New Mexico. Olympus Mons is a shield volcano, with slopes that rise gradually like those of Hawaiian volcanoes, and was created by eruptions of lava that flowed for long distances before solidifying. Mars also has many other kinds of volcanic landforms, from small, steep-sided cones to enormous plains coated in hardened lava. Some minor eruptions might still occur on the planet today.

Channels, valleys and gullies are found all over Mars, suggesting that liquid water might have once flowed across the planet's surface. Some channels are 100 kilometres (60 miles) wide and 2,000 kilometres (1,200 miles) long. Water may still lie in cracks and pores in underground rock. A 2018 study suggested that salty water below the Martian surface could hold a considerable amount of oxygen, which could support microbial life. But the amount of oxygen depends on temperature and pressure; temperature changes on Mars from time to time as the tilt of its rotation axis shifts.

Many regions of Mars are flat, low-lying plains. The low northern plains are among the flattest, smoothest places in the Solar System, potentially created by water that once flowed across the Martian surface. The northern hemisphere mostly lies at a lower elevation than the southern hemisphere, suggesting the crust may be thinner in the north than in the south. This difference between the north and south might be due to a very large impact shortly after the birth of Mars.

The number of craters on Mars varies from place to place, depending on how old the surface is. Much of the surface of the southern hemisphere is extremely old, and so has many craters – including the planet's largest, 2,300-kilometre (1,400-mile) Hellas Planitia – while the northern hemisphere is younger and so has fewer craters. Some volcanoes also have just a few craters, which suggests they erupted recently, with the resulting lava covering up any old craters. Some craters have unusual deposits of debris around them

MARS STATISTICS

Diameter: 6,791 kilometres (4,220 miles)

Gravity: 38 per cent of Earth's

Atmospheric composition: 95.32% carbon dioxide; 2.7% nitrogen; 1.6% argon; 0.13% oxygen; 0.08% carbon monoxide; traces of water, nitrogen oxide, neon, heavy water, krypton and xenon

Chemical composition:

Core: Iron, nickel and sulphur

Mantle: Peridotite (silicon, oxygen, iron and magnesium)

Crust: Volcanic rock basalt

Moons: Phobos and Deimos

Top: The ice cap which covers Mars' southern pole, composed of water and carbon dioxide

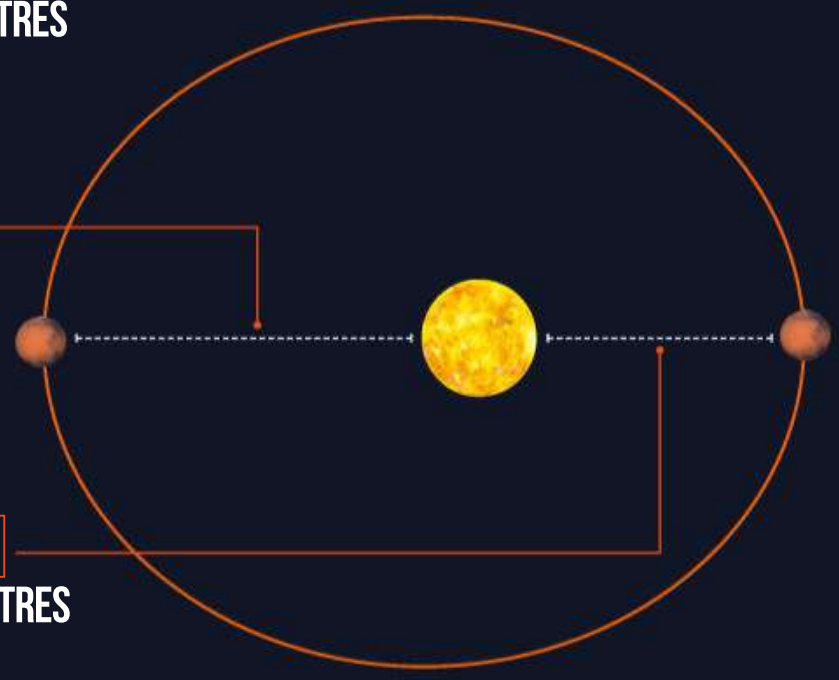
x2 Images © NASA/JPL-Caltech

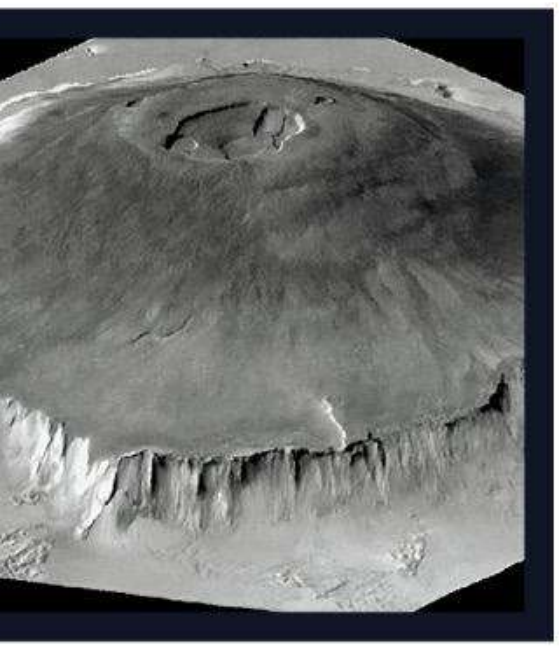
MARS' ORBITAL STATISTICS

227,936,640 KILOMETRES
(141,633,260 MILES)
AVERAGE DISTANCE FROM THE SUN

APHELION
249,200,000 KILOMETRES
(154,900,000 MILES)
FARTHEST DISTANCE FROM THE SUN

PERIHELION
206,600,000 KILOMETRES
(128,400,000 MILES)
CLOSEST SOLAR APPROACH





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Left: A 3D image of Olympus Mons, the largest known mountain in the Solar System

resembling solidified mudflows, indicating that the impactor may have hit underground water or ice.

In 2018, the European Space Agency's (ESA) Mars Express spacecraft detected what could be a slurry of water and grains underneath the icy Planum Australe. This body of water is said to be about 20 kilometres (12.4 miles) across. Its underground location is reminiscent of similar underground lakes in Antarctica, which have been found to host microbes. Mars Express also spied a huge, icy zone in Korolev crater. Vast deposits of what appear to be finely layered stacks of water ice and dust extend from the poles to latitudes of about 80 degrees in both Martian hemispheres. These were probably deposited by the atmosphere over long spans of time. On top of much of these layered deposits in both hemispheres are caps of water ice that remain frozen year-round.

Additional seasonal caps of frost appear in the wintertime. These are made of solid carbon dioxide, also known as 'dry ice', which has condensed from carbon dioxide gas in the atmosphere – Mars' thin air is about 95 per cent carbon dioxide by volume. In the deepest part of the winter, this frost can extend from the poles to latitudes as low as 45 degrees, or halfway to the equator. The dry ice layer appears to have a fluffy texture, like freshly fallen snow. Mars is much colder than Earth, in large part due to its greater distance from the Sun. The average temperature is

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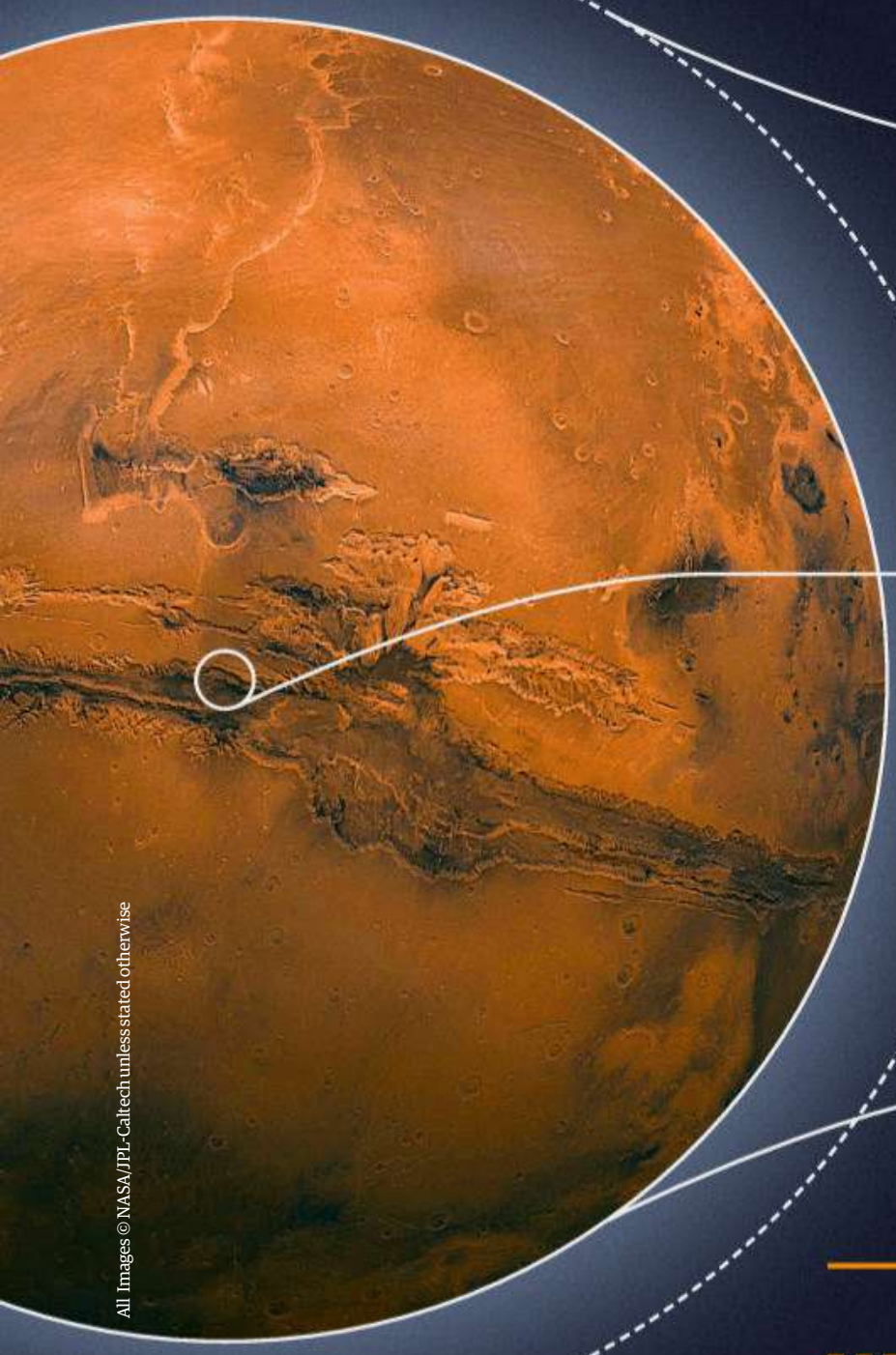
KEY MARS MISSIONS

Robots have been unlocking Mars' secrets for decades



MARS ODYSSEY
LAUNCH DATE: 7 APRIL 2001
ARRIVAL: 24 OCTOBER 2001

MARS RECONNAISSANCE ORBITER (MRO)
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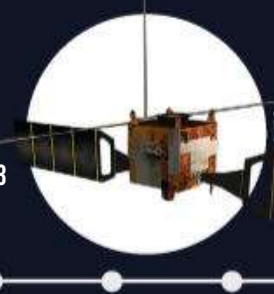
ARRIVAL: 10 MARCH 2006

MARS EXPRESS
LAUNCH DATE: 2 JUNE 2003
ARRIVAL: 25 DECEMBER 2003



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LAUNCH DATE: 10 JUNE 2003
ARRIVAL: 4 JANUARY 2004

OPPORTUNITY
LAUNCH DATE: 7 JULY 2003
ARRIVAL: 25 JANUARY 2004

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about -60 degrees Celsius (-80 degrees Fahrenheit), although it can vary from -125 degrees Celsius (-195 degrees Fahrenheit) near the poles during the winter to as much as 20 degrees Celsius (70 degrees Fahrenheit) at midday near the equator.

The carbon-dioxide-rich atmosphere of Mars is about 100 times less dense than Earth's on average, but it is nevertheless thick enough to support weather, clouds and winds. The density of the atmosphere varies seasonally, as winter forces carbon dioxide to freeze out of the Martian air. In the ancient past, the atmosphere was likely significantly thicker and able to support water flowing on the planet's surface. Over time, lighter molecules in the Martian atmosphere escaped under pressure from the solar wind, which affected the atmosphere because Mars doesn't have a global magnetic field. This process is being studied today by NASA's Mars Atmosphere and Volatile Evolution (MAVEN) mission. NASA's Mars Reconnaissance Orbiter found the first definitive detections of carbon-dioxide snow clouds, making Mars the only body in the Solar System known to host such unusual winter weather. The Red Planet also causes water-ice snow to fall from the clouds.

The dust storms on Mars are the largest in the Solar System, capable of blanketing the entire planet and lasting for months. One theory as to why dust storms can grow so big on Mars is because the airborne dust particles absorb sunlight, warming the Martian atmosphere in their vicinity. Warm pockets of air then flow towards colder regions, generating winds. Strong winds lift more dust off the ground, which in turn heats the atmosphere, raising more wind and kicking up more dust. These storms can pose serious risks to robots on the Martian surface. NASA's Opportunity rover 'died' after being engulfed in a giant 2018 storm, which blocked sunlight from reaching the robot's solar panels for weeks at a time.

Mars lies farther from the Sun than Earth does, so the Red Planet has a longer year – 687 days compared to 365 for our home world. But the two planets have similar day lengths; it takes about 24 hours and 40 minutes for Mars to complete one rotation around its axis. The axis of Mars, like Earth's, is tilted in relation to the Sun. This means that like Earth, the amount of sunlight falling on certain parts of the Red Planet can vary during the year, giving Mars seasons.

However, the seasons that Mars experiences are more extreme than Earth's because the Red Planet's elliptical, oval-shaped orbit is more elongated than that of any of the other major planets. When Mars is closest to the Sun, its southern hemisphere is tilted towards our star, giving the planet a short, warm summer, while the northern hemisphere experiences a short, cold winter. When Mars is farthest from the Sun, the northern hemisphere is tilted towards it, giving the planet a long, mild summer, while the southern hemisphere experiences a long, cold winter.

The tilt of the Red Planet's axis swings wildly over time because it's not stabilised by a large moon. This has led to different climates on the Martian surface throughout its history. A

Below: Perseverance records the Ingenuity helicopter's flights over the Martian surface for Earth viewing

x2 Images © NASA/JPL-Caltech

MEASURING THE VITALS OF MARS

Nothing beats the versatility of the InSight Mars lander. The mission is equipped with an array of sensors that have been described as 'taking the vitals' of Mars. They resulted in immediate success, with the detection of seismic activity – in the form of marsquakes – passing through the Red Planet.

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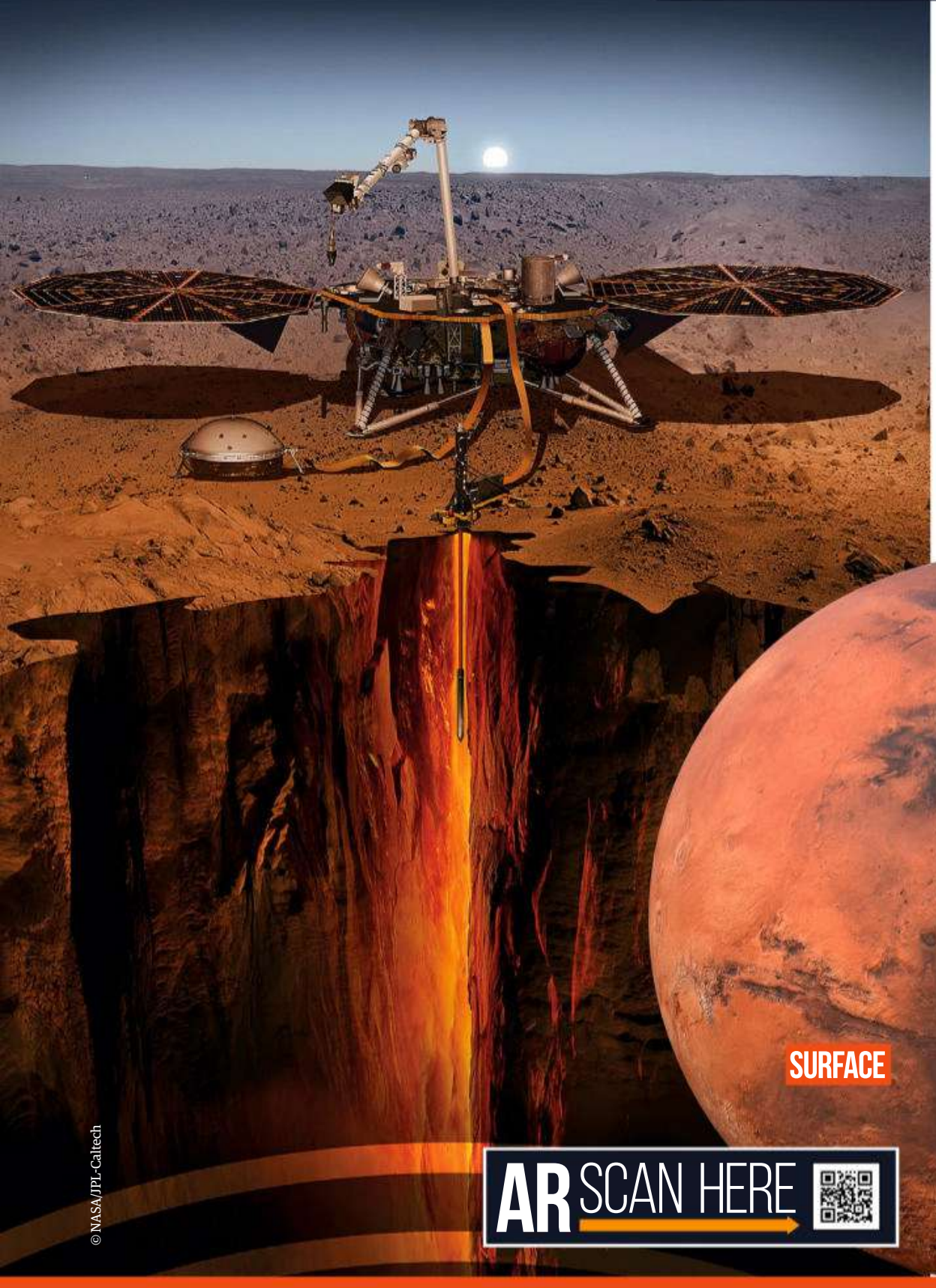
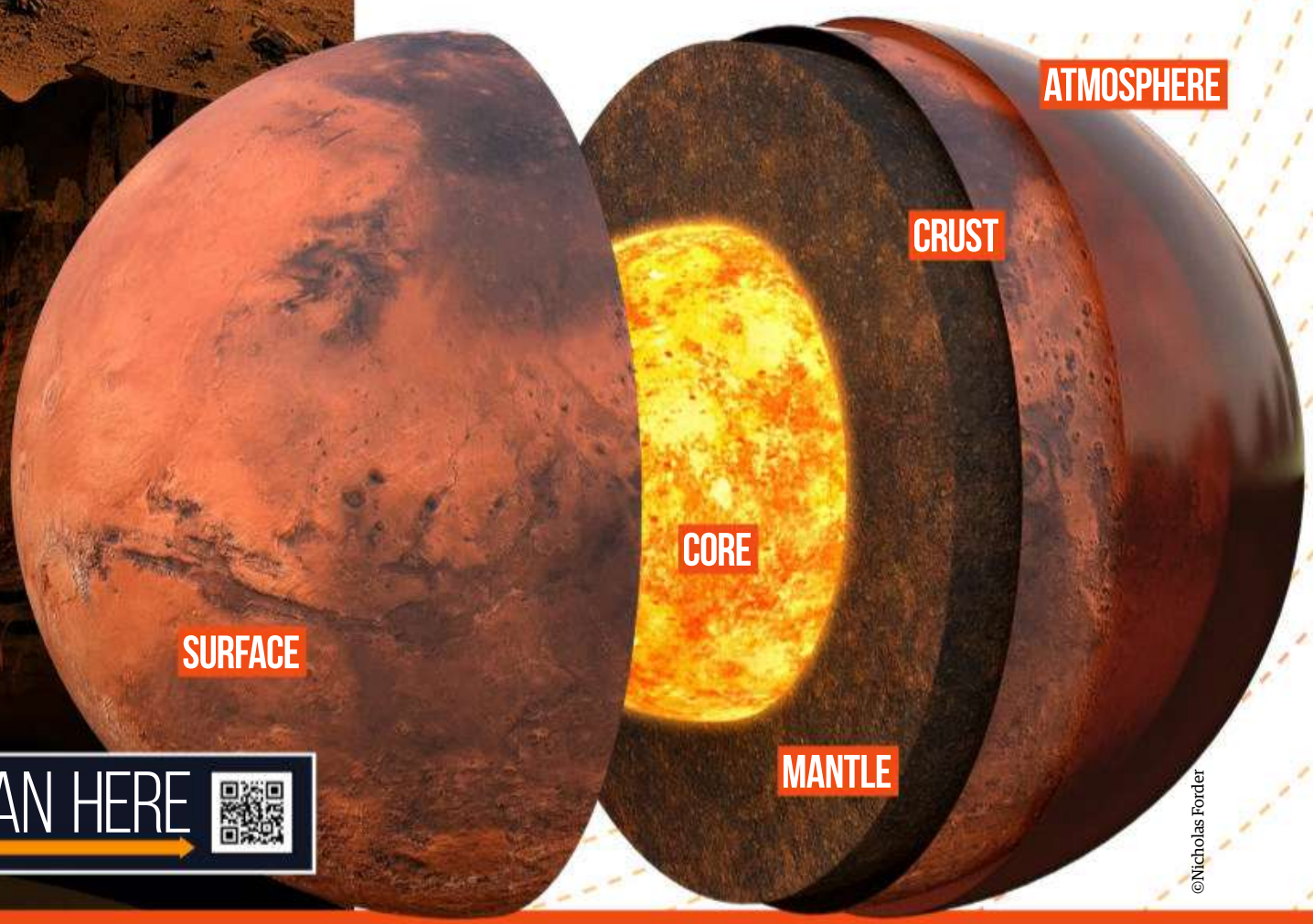


Above: Astronauts working safely on the surface of Mars with a pressurised vehicle in the background

Below: Mars is thought to have a solid core like Earth



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2017 study suggests that the changing tilt also influenced the release of methane into Mars' atmosphere, causing temporary warming periods that allowed water to flow.

Mars is 6,791 kilometres (4,220 miles) in diameter – far smaller than Earth, which is 12,756 kilometres (7,926 miles) wide. The Red Planet is about ten per cent as massive as our home, with a gravitational pull 38 per cent as strong. A 45-kilogram person here on Earth would weigh just 28 kilograms on Mars, but their mass would be the same on both planets. The atmosphere of Mars is 95.32 per cent carbon dioxide, 2.7 per cent nitrogen, 1.6 per cent argon, 0.13 per cent oxygen and 0.08 per cent carbon monoxide, with minor amounts of water, nitrogen oxide, neon, heavy water, krypton and xenon.

Mars lost its global magnetic field about 4 billion years ago, leading to the stripping of much of its atmosphere by the solar wind. But there are regions of the planet's crust today that can be at least ten times more strongly magnetised than anything measured on Earth, suggesting those regions are remnants of an ancient global magnetic field. Mars likely has a solid core composed of iron, nickel and sulphur. The mantle is probably similar to Earth's in that it's composed mostly of peridotite, made up of silicon, oxygen, iron and magnesium. The crust is probably made of the volcanic rock basalt, which is also common in the crusts of Earth and the Moon, although some crustal rocks, especially in the northern hemisphere, may be a form of andesite, a volcanic rock that contains more silica than basalt does.

NASA's InSight lander has been probing the Martian interior since touching down near the

planet's equator in November 2018. InSight measures and characterises marsquakes, and mission team members are tracking wobbles in Mars' tilt over time by precisely tracking the lander's position on the planet's surface. Data has revealed key insights about Mars' internal structure. InSight team members recently estimated that the planet's core is 1,780 to 2,080 kilometres (1,110 to 1,300 miles) wide. InSight's observations also suggest that Mars' crust is 24 to 72 kilometres (14 to 45 miles) thick on average, with the mantle making up the rest of the planet's non-atmospheric volume. For comparison, Earth's core is about 7,100 kilometres (4,400 miles) wide – bigger than Mars itself – and its mantle is roughly 2,900 kilometres (1,800 miles) thick. Earth has two kinds of crust, continental and oceanic. Average thicknesses are about 40 kilometres (25 miles) and eight kilometres (five miles) respectively.

The two moons of Mars, Phobos and Deimos, were discovered by American astronomer Asaph Hall over the course of a week in 1877. Hall had almost given up his search for a moon of Mars, but his wife urged him on. He discovered Deimos the next night, and Phobos six days after that. He named the moons after the sons of the Greek war god Ares – Phobos means 'fear', while Deimos means 'dread'. Both are likely made of carbon-rich rock mixed with ice and are covered in dust and loose rocks. They are tiny next to Earth's Moon and are irregularly shaped since they lack enough gravity to pull themselves into a more circular form. The widest Phobos gets is about 27 kilometres (17 miles), and the widest Deimos gets is roughly 15 kilometres (nine miles).

Both moons are pockmarked with craters from meteor impacts. The surface of Phobos also possesses an intricate pattern of grooves, which may be cracks that formed after an impact created the moon's largest crater – a hole about ten kilometres (six miles) wide, nearly half the width of Phobos. The two satellites always show the same face to their parent planet, just as our Moon does to Earth. It remains uncertain how Phobos and Deimos formed. They may be former asteroids that were captured by Mars' gravitational pull, or they may have formed in orbit around Mars at roughly the same time the planet came into existence. Ultraviolet light reflected from Phobos provides strong evidence that the moon is a captured asteroid. Phobos is gradually spiralling towards Mars, drawing about 1.8 metres (six feet) closer to the Red Planet each century. Within 50 million years, Phobos will either smash into Mars or break up and form a ring of debris around the planet.

The first person to observe Mars with a telescope was Galileo Galilei in 1610. In the following century, astronomers discovered the planet's polar ice caps. In the 19th and 20th centuries, some – most famously Percival Lowell – believed they saw a network of long, straight canals on Mars that hinted at a possible civilisation. However, these sightings proved to be mistaken interpretations of geological features.

Right: The Perseverance rover captures a picture as it selects a boulder to drill

x3 Images © NASA/JPL-Caltech

A number of Martian rocks have fallen to Earth over the aeons, providing scientists with a rare opportunity to study pieces of Mars without having to leave our planet. One of the most controversial finds was Allan Hills 84001 (ALH84001) – a Martian meteorite that may contain tiny fossils and other evidence of Mars life. Other researchers have cast doubt on this hypothesis, but the team behind the famous 1996 study have held firm to their interpretation, and the debate about ALH84001 continues today. In 2018, a separate meteorite study found that organic molecules – the carbon-containing building blocks of life, although not necessarily evidence of life itself – could have formed on Mars through battery-like chemical reactions.

Robotic spacecraft began observing Mars in the 1960s, with the US launching Mariner 4 in 1964 and Mariners 6 and 7 in 1969. Those early missions revealed Mars to be a barren world, without any signs of life or the civilisations people such as Lowell had imagined there. In 1971, Mariner 9 orbited Mars, mapping about 80 per cent of the planet and discovering its volcanoes and canyons. The Soviet Union also launched numerous Red Planet spacecraft in the 1960s and early 1970s, but most of those missions failed. Mars 2 and Mars 3 operated successfully, but were unable to map the surface due to dust storms. NASA's Viking 1 lander touched down on the surface of Mars in 1976, pulling off the first successful landing on the Red Planet. Its twin, Viking 2, landed six weeks later in a different Mars region. The Viking landers took the first close-up pictures of the Martian surface, but found no strong evidence for life. Again, however, there has been debate: Gilbert Levin, principal investigator of the Vikings' Labeled Release life-detection experiment, forever maintained that the landers spied evidence of microbial metabolism in the Martian dirt.

The next two craft to successfully reach the Red Planet were Mars Pathfinder, a lander, and Mars Global Surveyor, an orbiter, both NASA craft that launched in 1996. A small robot on board Pathfinder, called Sojourner, became the first wheeled rover ever to explore the surface of another planet, venturing over the planet's surface and analysing rocks for 95 Earth days.

Right: NASA engineers working on a heat shield that could protect human visitors to Mars

Below: Jezero crater snapped by Perseverance. Researchers uncovered that the crater is actually an ancient lake

x2 images © NASA/JPL-Caltech

In 2001, NASA launched the Mars Odyssey orbiter, which discovered vast amounts of water ice beneath the Martian surface, mostly in the upper metre (three feet). It remains uncertain whether more water lies underneath, since the probe cannot see water any deeper.

In 2003, Mars passed closer to Earth than it had at any time in the past 60,000 years. That same year, NASA launched two golf-cart-sized rovers, named Spirit and Opportunity, which explored different regions of the Martian surface after touching down in January 2004. Both rovers found many signs that water once flowed on the surface. Spirit and Opportunity were originally tasked with three-month surface missions, but both kept roving for far longer than that. NASA didn't declare Spirit dead until 2011, and Opportunity was still going strong until that dust storm hit in mid-2018.

Next, in 2008, NASA sent a lander called Phoenix to the far-northern plains of Mars. The robot confirmed the presence of water ice in the near subsurface, among other finds. In 2011, NASA's Mars Science Laboratory mission sent the Curiosity rover to investigate Mars' past potential to host life. Not long after landing inside the Red Planet's Gale crater in August 2012, the car-sized robot determined that the area hosted a long-lived, potentially habitable lake-and-stream system in the ancient past. Curiosity has also discovered complex organic molecules and documented seasonal fluctuations in methane concentrations in the atmosphere.

But NASA isn't the only interested party. The ESA has two spacecraft orbiting the planet: Mars Express and the Trace Gas Orbiter. Also, in September 2014, India's Mars Orbiter Mission reached the Red Planet, making it the fourth nation to successfully enter orbit around Mars.

In November 2018, NASA landed a stationary craft called InSight on the surface. InSight is investigating Mars' internal structure and composition, primarily by measuring and characterising marsquakes. NASA also launched the life-hunting Perseverance rover in July 2020. Perseverance landed on the floor of Mars' Jezero crater in February 2021 along with a tiny test helicopter known as Ingenuity.

2020 also saw the launch of the United Arab Emirates' first Mars mission, Hope, and China's first fully homegrown Mars effort, Tianwen-1. Hope arrived in February 2021 and is studying the atmosphere, weather and climate. Tianwen-1, which consists of an orbiter and a lander-rover duo, also reached Mars orbit in February 2021.

Robots aren't the only ones getting a ticket to Mars. A workshop group of scientists from government agencies, academia and industry have determined that a NASA-led manned mission to Mars should be possible by the 2030s. Robotic missions have seen much success in the past few decades, but it remains a considerable challenge to get people to Mars. With current technology, it would take at least six months for people to travel to Mars. Red Planet explorers would therefore be exposed for long stretches to deep-space radiation and to microgravity, which has devastating effects on the human body. Performing activities in the moderate gravity of Mars could prove extremely difficult after many months in microgravity. Research into the effects of microgravity continues on the International Space Station in preparation.

NASA isn't the only entity with crewed Mars aspirations. Other nations, including China and Russia, have also announced their goals for sending humans to the Red Planet. And Elon Musk, the founder and CEO of SpaceX, has long stressed that he established the company back in 2002 primarily to help humanity settle the Red Planet. SpaceX is currently developing and testing a fully reusable deep-space transportation system called Starship, which Musk believes is the breakthrough needed to get people to Mars at long last.

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Charles is a contributing writer for **space.com** and **Live Science**. He covers all things human origins and astronomy as well as physics.

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MARTIAN AIRSHIPS

A new NASA study has the aim of exploring the Red Planet with the help of empty balloons

While the Martian rovers Spirit, Opportunity and Curiosity have explored further afield than ever before, the process is frustratingly slow. Curiosity's top speed is only 200 metres (650 feet) per day, partly due to the difficulty of controlling a robot with a 20-minute round trip communications delay, limiting the reach of our exploration. Numerous proposals for flying probes of various types have been put forward to explore different bodies in the Solar System. Proposals include free-flying balloons - which have already been deployed on Venus - dirigible airships, gliders and even hopping probes that jump across terrain. But NASA's latest airship study is unique; it will fly on a vacuum lift.

Balloons and airships float in an atmosphere by displacing some of the atmosphere with something lighter - just like the way boats float by displacing water (with their hulls) for air (the space inside their hulls). On Earth we have mostly used hot air - where the air inside the balloon becomes lighter than the surrounding air as it heats up - or lift gases like hydrogen and helium. Lift gases work because they are less dense than air, but at the same pressure, so flying balloons are not tightly inflated like a party balloon. At standard sea-level pressure, every cubic metre contains 1.292 kilograms of air, but a cubic metre of hydrogen or helium contains just 90 or 178 grams respectively, producing a lift of 1.202 or 1.114 kilograms.

As lift depends on the mass of gas you can push out of the way, in theory the best possible balloon would have nothing in it at all, providing the full 1.292 kilograms of lift for every cubic metre. Indeed, some of the first scientists to think about balloons considered this, but the lift gases are also there to hold the shape of the balloon against the surrounding pressure. On Earth a vacuum balloon is impractical because it would have to be far heavier than it could lift to be strong enough to hold up against the atmospheric pressure around it. But things could be different on Mars.

That is what Professor John-Paul Clarke of the University of Texas at Austin is investigating, and Mars offers a number of advantages to the potential vacuum balloonist. Its atmosphere is predominately carbon dioxide, which is much denser than air. It's very cold, which also helps atmospheric density, yet at the same time Mars' surface pressure is only 1/160th of Earth's. These factors mean that the Martian atmosphere is a better mix for supporting balloons – in Venus' dense carbon-dioxide atmosphere, normal Earth air works as a lifting gas – and that a vacuum balloon doesn't have to support such a crushing load. Clarke's proposal is for a rigid balloon with two layers – an inner shell containing the vacuum supported by a lattice of lightweight beams connecting to the outer shell.

A vacuum airship's greatest advantages for exploring Mars are its ability to travel quickly regardless of terrain and the fact it doesn't need a finite reserve of lift gas. Vacuum is an infinite resource, so all the airship needs is a source of power for a pump to empty the envelope, and its outer shell provides more than enough area for solar panels to provide electricity. This means it could fly and land repeatedly without running out of gas, even offering the prospect of future Martian transport ships that essentially fly for free and can be 'filled' anywhere on the planet. Although they sound like something from fiction, vacuum-filled Zeppelins could be the backbone of the Martian transport network.

1 SOLAR POWER
The large surface area of the airship body can be covered with solar cells to provide electricity for the pump, propulsion and the science payload.

2 MARTIAN ATMOSPHERE
The Martian atmosphere offers a unique opportunity in the Solar System to exploit vacuum as a lifting agent because it is mostly cold, heavy carbon dioxide, but at a low overall pressure.

3 AERIAL AUTONOMY
Martian rovers move so slowly because the 20-minute round trip delay makes it impossible to control them directly. Not only can an airship travel more quickly, it can do so with less risk of accident.

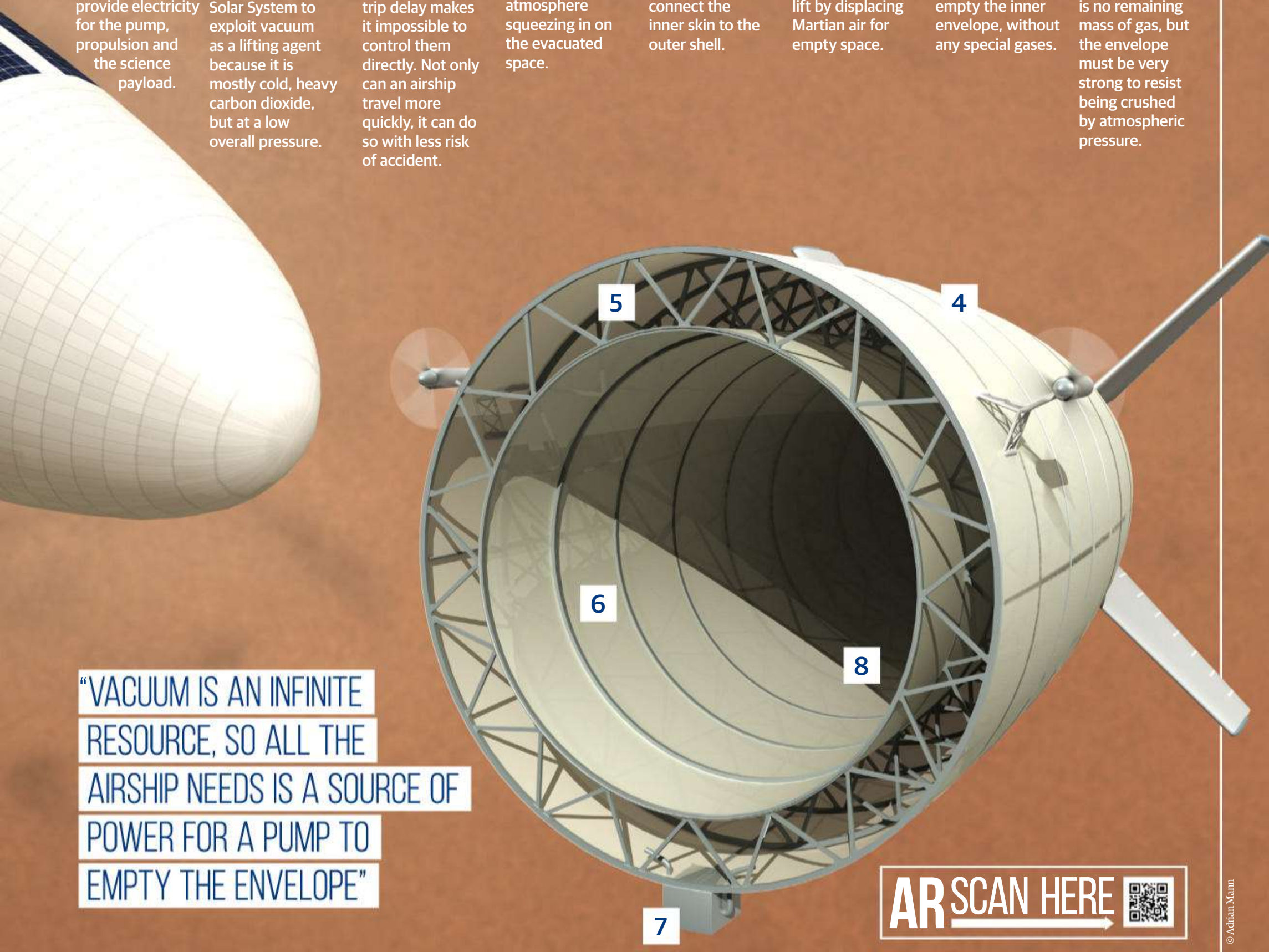
4 OUTER SHELL
The external shell of the vacuum airship will support the load of the atmosphere squeezing in on the evacuated space.

5 GIRDER LATTICE
A latticework of lightweight girders, most likely a carbon composite, connect the inner skin to the outer shell.

6 INNER HULL
The inner envelope is the volume where the atmosphere is removed, creating lift by displacing Martian air for empty space.

7 PUMP
In principle, all the airship needs to take flight is an electrically powered pump to empty the inner envelope, without any special gases.

8 VACUUM
Vacuum offers the greatest lifting potential of any lifting agent as there is no remaining mass of gas, but the envelope must be very strong to resist being crushed by atmospheric pressure.



"VACUUM IS AN INFINITE RESOURCE, SO ALL THE AIRSHIP NEEDS IS A SOURCE OF POWER FOR A PUMP TO EMPTY THE ENVELOPE"

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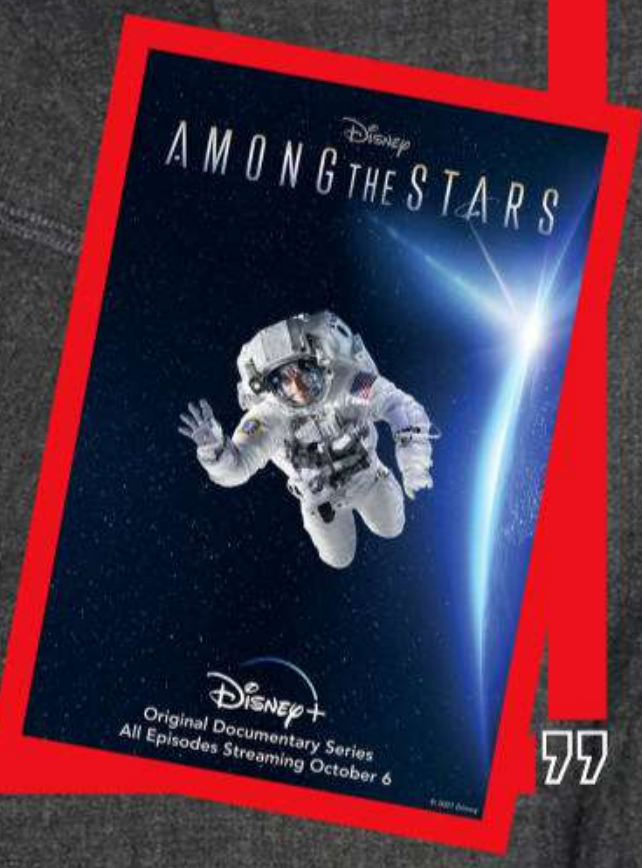
INTERV

BIO

Ben Turner

Turner is a director, producer and founding partner of Fulwell 73 Productions. He has worked across a wide range of genres in documentary, drama, comedy and music. His latest project, Disney+'s *Among the Stars*, chronicles NASA's quest to replace failing cooling pumps on a cosmic-ray detection experiment, the Alpha Magnetic Spectrometer (AMS), on the International Space Station. The six-part show is centred around astronaut Chris Cassidy, astrophysicist Dr Samuel Ting, AMS project manager Ken Bollweg and a global cast of talented space professionals. The full series of *Among the Stars* is available to watch on Disney+.



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BEN TURNER

“WE CAN BE AMAZING IF WE WANT TO BE”

Turner takes us behind the scenes of his docuseries *Among the Stars*, available now on Disney+

Interviewed by Daisy Dobrijevic

You've made quite a lot of documentaries, including sports documentaries. How did you find yourself pivoting over to a space documentary?

The more I've done, the more I've had license to indulge in my passions. One of the great privileges of being a filmmaker is to get to see the world through other people's eyes. I've always wanted to make something about space, and I've been trying to get into NASA for a long time.

We used to make a lot of music videos with One Direction, and we realised that they were so big that they could open more or less any door for us – like NASA. And they came to us once with a song called *Drag Me Down*, and we were like, well, what's the opposite of drag me down? Launch on a spaceship! We pitched it, they liked it and we got into the Johnson Space Center just to shoot the One Direction music video, and that was the first time I ever got in there. The recce day was one of the greatest days of my life.

I feel that sports documentaries have come a long way. When we started, it was quite a difficult pitch because the people you were pitching to would just be like, “why don't you just watch the sport” and “if everyone knows the result, who is going to care?”. We had to think long and hard about how to make them interesting, with a kind of resonance and significance of the story beyond the sport itself. After we made *Sunderland 'Til I Die*, we were like, this method of storytelling really works. What other teams could we follow? Well... NASA. I thought surely if it's interesting to watch a load of people kick a ball around, it's going to be interesting watching them set up and go on a mission. It's actually quite a natural path from sports documentaries to NASA, even though it may seem a bit random.

***Among the Stars* features people from many areas of the space industry. Has the production of this documentary given you a greater appreciation of all those involved 'behind the scenes' on these monumental space missions?**

Massively. Every time you speak to astronauts, they're very humble. They'll say to you, “we are just the tip of the iceberg”. And that iceberg is a huge group of people, in lots of different rooms, each with different tasks, who basically spend their lives going: “If this isn't ready by Wednesday we're all screwed.” That's really dramatic, and it's a really amazing way of building up what the stakes are so that when the astronauts go out on the spacewalk you'll understand what they're doing.

I love it, but if you've ever watched an extravehicular activity, it's like watching paint dry. I sit there being like, I really should be interested in this, but I don't know what's happening. It's boring but it should be interesting. That was the equation to me, and the way to make it interesting is what are the stakes here? What is happening? Getting into the iceberg and meeting the people behind the mission was the answer.

Right: Chris Cassidy completed ten spacewalks throughout his career

© NASA

> EVERY TIME YOU SPEAK TO ASTRONAUTS, THEY'RE VERY HUMBLE

What did you hope to achieve?

That's really an answer in two parts. What I really wanted to get from it was to get to hang out with people from NASA. That's really my honest answer. I got to hang out with those people, but I got robbed of the launches and a lot of it because of coronavirus, which I will never really get over because I'm very fond of Chris [Cassidy] and I'm lucky enough to call him a friend. I didn't get to see my friend go off into space, and that hurts. The bigger picture is that I want to go to space. I want to meet people to help me go to space, so that's still a work in progress.

In terms of the filmmaking side of it, there are a few ways to answer that. In terms of space, I just think it's so fascinating, I can't believe anyone wouldn't. My career really is me being like, "this is so amazing". I'm like that annoying dude in the pub but with more resources to try and prove what I think is interesting is interesting.

But I do think that when we were making it, it was an awful time in the world. Politics in America and here in the UK were just really awful – the tone of it and what everyone was doing. People felt awful and we were not able to disagree constructively; there was just despair of humanity.

But I find this inspirational, and I think human beings are terrible, but they are also amazing, even in a pandemic. There are good people, and I find that inspiration. It exists in this world and it exists among those people there at NASA working≈on this mission, coming together to do amazing things.

Fundamentally, I would like people to watch this show and be reminded that we can be amazing if we want to be. It's happening in the world. If you get on board with those people, if you want to be a part of that, it's there. The more of us that do that, the better. That will be what I want people to take away from the show.

What was the biggest challenge you faced when producing *Among the Stars*?

Getting it away was the biggest challenge, just aligning everything. The reason why I say aligning is if you want to make a show with NASA, they'll say you have to have funding and distribution to get the access. But you can't pitch a broadcaster to give you millions of dollars to make a series and then say, "we'll chat about it once you've given me that money". It was a very tricky thing to try and fit those together, and NASA can't really bend on these things because they're a government agency.

Same as when coronavirus came along. A lot of the time when I work, someone says no, and you're like, "yeah, but really? What if I do it like this?" You hustle; that's a lot of what the game is. There's limited hustle with someone like NASA because the rules are the rules. In various forms, you come up against that along the way, and I

© NASA

Above: *Among the Stars* chronicles NASA's mission to replace failing cooling pumps on an ISS experiment

Left: NASA astronaut Andrew Morgan during repairs on the AMS

Below: Cassidy in the ISS' Cupola during his final NASA flight, Expedition 63

I'm upset". I was like, "there's no one in the world who thinks you're not upset. You come on camera and go yes, that's fine. Do you think anyone will be sitting there watching thinking 'oh yeah, of course, he's fine'." That was what we were working towards, that kind of emotion.

What surprised you most when filming *Among the Stars*, good or bad?

Professor Ting and that whole storyline was just like a gift from heaven. I remember sitting in that first meeting where he took that meeting room apart and I just couldn't believe it. I couldn't believe I was allowed to film it and that they were cool with it. Just Ting in general.

The first time I ever met him, the first meeting I ever shot was in Germany. He's addressing a whole room, and it's literally the first time we've ever turned the camera on, and I'm sitting there with my cinematographer, a guy called Diego Rodriguez who I've worked with for a long time. I whispered something about the frame and Ting stopped the meeting, looked at me and was like, "can you please be quiet. There's a meeting going on." It was awful; I wanted to just shrink and become invisible.

I really didn't think we were going to get on very well. But after the meeting, everyone in the NASA team was like, "ahh, you got Tinged". So it was like a right of passage. It sort of really helped me become a part of their team. But he was really just amazing.

Now that spaceflight is becoming more accessible, how does it feel to have been documenting the lives of those involved with NASA at this time of change?

Something that I wasn't really aware of until I was deep into the process was that I was actually documenting a very significant moment in space travel and potentially human history. Chris' first shuttle mission helped build the ISS, and on his last mission to the ISS, the first commercial crew came on while he was out there.

I don't need to tell you how exciting it all is, but it's a real changing of the guard between NASA, who are across everything, to whatever the future is going to hold. And documenting that moment was pretty amazing. That was a really lovely surprise for me, because as a documentary filmmaker you hope to document something significant

When the documentary was finished, we showed it in IMAX at the Johnson Space Center, and we put on a screening for everyone involved. Honestly, I was on the verge of tears the entire time because there are all these people I've met who have put a lot of trust in me. And to show them that and to have them thank me for making it, it was really amazing.

Has *Among the Stars* given you a new perspective on the space industry?

It's how I hoped it would be. There's a lot to it, and I by no means got to see everything. There's a kind of higher level than the stuff I've documented, which is quite political and all about financing stuff. I got a view of a group of people doing things that I hoped they would be doing in the way they were doing them, and I'm lucky enough to count some of them as my friends. I'm more fascinated by it now than I was even going in. More is on the horizon, and it's so exciting. I couldn't be more fascinated.

came to realise why no one had made this kind of show beforehand.

But NASA has to manage risk. Once we were in it was amazing, because once you knock on the doors of the people in the iceberg, they're all geeks like us. They're like, "oh really, you're interested in this?" I'm like, "dude, all day long. I'm fascinated. Talk to me". And it would just spiral from there.

You were able to capture a different side to the astronauts – one we don't usually see – for example when Cassidy got some sad news and was visibly upset. Were you surprised with how much emotion you managed to capture?

It was what I was hoping for. The stuff we make at Fulwell always has an emotional heart to it, and that's what I was setting out to achieve, but I think the level of how much people opened up was surprising. There was a moment where Chris was like, "oh, I don't know if I really want to show that

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Focus on

PLUTO'S ATMOSPHERE IS STARTING TO DISAPPEAR

The dwarf's nitrogen-rich atmosphere is going through a strange transformation

Reported by Chelsea Gohd

The icy dwarf planet, which lies over 4.8 billion kilometres (3 billion miles) away from Earth in the Kuiper Belt, caught astronomers' attention as it passed in front of a star back in 2018.

With the star backlighting Pluto, a team of researchers was able to make observations of the dwarf planet and its atmosphere. With this unique view, they came to a surprising conclusion: they found evidence that Pluto's atmosphere is starting to disappear.

Using telescopes at multiple sites in both the US and Mexico, the team observed Pluto and its thin atmosphere, which is primarily made of nitrogen. Pluto's atmosphere is supported by the vapour pressure of ices on the dwarf planet's surface; if ice warms up on Pluto, it can dramatically alter the density of its atmosphere.

For about 25 years, Pluto has been moving farther and farther away from the Sun, so its surface temperature has been going down. And with these recent observations, the researchers found evidence showing that Pluto's atmosphere is actually refreezing back onto its surface as the dwarf planet gets colder and colder. Pluto is so far from the Sun that as time goes on it will get distinctly farther away before getting closer to the Sun in other regions of its immense orbit.

© NASA

Thanks to a phenomenon known as thermal inertia, Pluto's surface pressure and atmospheric density continued to rise until 2018. Essentially, Pluto had residual heat from when it was closer to the Sun. However, the inertia is starting to wear off, and as Pluto gets colder, more and more of its atmosphere will freeze back onto its surface and 'disappear'.

"An analogy to this is the way the Sun heats up sand on a beach," said Southwest Research Institute (SwRI) staff scientist Leslie Young, who studies the interaction between icy Solar System bodies and their surfaces and atmospheres.

"Sunlight is most intense at high noon, but the sand then continues soaking up the heat over the course of the afternoon, so it's hottest in the late afternoon. The continued persistence of Pluto's atmosphere suggests that nitrogen ice reservoirs on Pluto's surface were kept warm by stored heat under the surface. The new data suggests they are starting to cool," Young said.

The researchers watched the star fade as Pluto moved in front of it and then come back into view once the dwarf planet had passed. Using the rate that the star came in and out of view – a transition that lasted about two minutes – they were able to determine the density of the dwarf planet's atmosphere.

This method relies on what is known as an 'occultation' – when one cosmic object is hidden by another passing in front of it. Studying occultations is an old and well-worn technique in the world of astronomy, and researchers have used it to study Pluto's atmosphere since 1988, Eliot Young, a SwRI senior program manager, said.

"New Horizons obtained an excellent density profile from its 2015 flyby, consistent with Pluto's bulk atmosphere doubling every decade, but our 2018 observations don't show that trend continuing from 2015," Young added.

In observing Pluto as it passed in front of the star, the team noticed a 'central flash' in the middle of the path of the dwarf planet's shadow. The flash, caused by Pluto's atmosphere refracting light into the centre of the shadow, changed the light curve that usually happens during occultation from a U shape into a W.

"The central flash seen in 2018 was by far the strongest that anyone has ever seen in a Pluto occultation," said Young. "The central flash gives us very accurate knowledge of Pluto's shadow path on Earth."

© Getty

Left: Starlight from behind the dwarf highlighted its atmosphere

Main: Pluto's irregular orbital path causes it to change temperature as it circles the Sun

"NITROGEN ICE RESERVOIRS ON PLUTO'S SURFACE WERE KEPT WARM BY STORED HEAT" LESLIE YOUNG

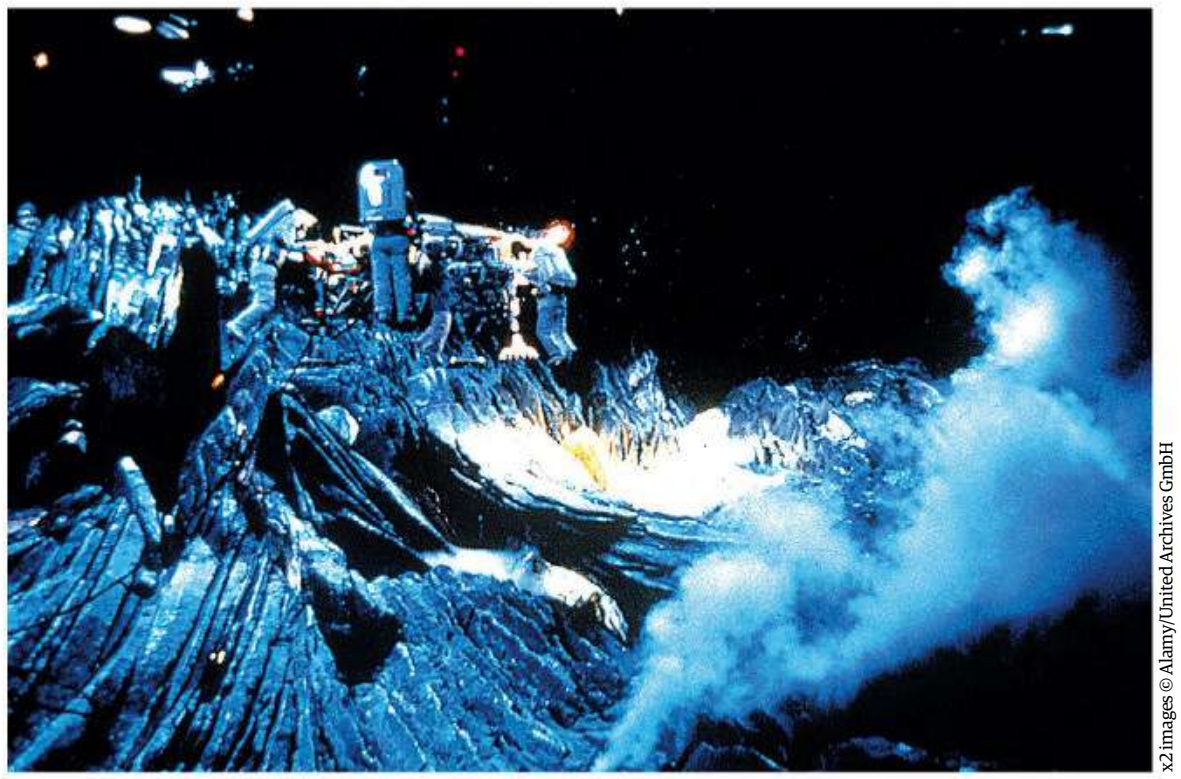
THE MOST REALISTIC SPACE MOVIES

© Getty

THESE ARE THE MOST SCIENTIFICALLY ACCURATE SPACE MOVIES WE'VE SEEN... YOU WON'T FIND *ARMAGEDDON* ANYWHERE NEAR THIS LIST

Written by Dan Whitehead

Put away your warp drives and get out of here with your midi-chlorians, because we're running down our list of the top five most realistic space movies. Hollywood doesn't have a great reputation when it comes to scientific accuracy, but that's okay. A movie's primary function should be to entertain by telling a gripping story, not to be a big-screen textbook. Of course, when science is ignored to such a degree that a film becomes laughably unbelievable, then it becomes a problem. To list those movies would likely fill the entire magazine, as pulp-fiction spaceships zip from one galaxy to another in the space of a day and lasers shoot glowing bullet-like projectiles at suspiciously humanoid aliens. Let's celebrate the films that get it right and the movies that manage to spin a good yarn without abandoning scientific reality. Here are our top five realistic space movies.



x2 images © Alamy/United Archives GmbH

DEEP IMPACT

RELEASED: 1998 **DIRECTOR:** Mimi Leder
CAST: Robert Duvall, Téa Leoni and Elijah Wood

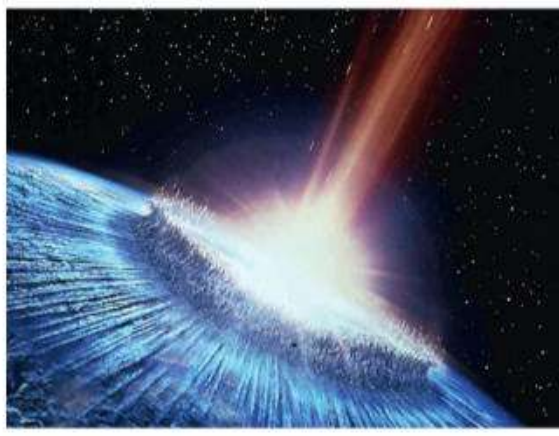
Above: The crew pack the comet with nuclear bombs to destroy it

Below: The titular impact striking planet Earth

Disaster movies rarely trouble themselves with scientific accuracy, correctly assuming most audiences want to see that attractive all-star cast surviving fireballs by the skin of their teeth. That makes *Deep Impact*'s level of authentic detail all the more impressive. While it definitely stretches the truth in pursuit of spectacular effects sequences, unlike its rival asteroid flick, Michael Bay's bombastic *Armageddon*, *Deep Impact* is a far more sober and realistic depiction of what an extinction-level event would look like.

A teen amateur astronomer (Elijah Wood) detects an errant comet on a collision course with Earth, and soon the US president (Morgan Freeman) is conferring with his experts to see what can be done. The answer: not much. Unlike *Armageddon*'s save-the-world cheerleading, an attempt to destroy *Deep Impact*'s harbinger of doom fails spectacularly, and the film becomes more about how we cope with disaster than how we avert it.

The movie's science regarding the comet is pretty solid, and it doesn't overexaggerate the threat for the sake of glossy action scenes. The impact scenes are broadly true to what impacts of that size would actually do to the planet's atmosphere, oceans and cities, even if seeing Wood outrunning a tsunami on a motorbike is a step too far. It's a film that didn't need to be even remotely realistic, so the efforts it makes in that department are all the more welcome.



DID YOU KNOW?

It's purely a coincidence that *Deep Impact* and NASA's Deep Impact mission share a name. Apparently the two were named independently of each other around the same time. NASA's Deep Impact was launched on 12 January 2005 with a primary mission to probe beneath the surface of comet Tempel 1. The spacecraft released an impact probe that collided with Tempel 1, revealing the comet was very porous – about 75 per cent empty space. After the primary mission was complete, Deep Impact made multiple flybys of Comet 103P/Hartley.

INTERSTELLAR

RELEASED: 2014 **DIRECTOR:** Christopher Nolan **CAST:** Matthew McConaughey, Anne Hathaway and Jessica Chastain

The search for an alternative home for humanity has been the basis of many a sci-fi story, but few have been as evocative – or as grounded in theoretical physics – as Christopher Nolan's quantum melodrama *Interstellar*. Matthew McConaughey stars as Joe Cooper, a melancholy former astronaut who is scratching out a living as a farmer on a near-future Earth rapidly turning into an arid dust bowl. His retirement is brought to an end as he's recruited for an experimental deep-space mission to locate new habitable planets through a wormhole.

Though much of what it depicts is purely theoretical, such as the mind-bending finale built around the time-warping effects of wormholes, Nolan went out of his way to make sure that he was at least working from real scientific theories. For the film's visually disorientating representations of what it would look like to travel past the event horizon of a wormhole, Nolan turned to Nobel Prize-winning physicist Kip Thorne, who put together equations that the computer effects team then used to generate their dizzying space-time distortions. Until we find a way to actually travel past light speed, we're not going to know how accurate those effects really were, but by using cutting-edge astrophysics as his basis, rather than just what looked cool, Nolan was already ahead of the sci-fi curve.

The time dilation inherent in Einstein's theory of relativity not only advances the plot, but underscores the painful human drama. In one particularly heartbreaking scene, McConaughey breaks down in tears as he watches decades of saved video messages from his son, knowing that although he is only months away from Earth from his perspective, his child has grown old and will die long before he can return home. This is a potent and moving illustration of the sacrifices that deep-space travel will involve.

Right: The film's depiction of a black hole is very close to the real image of one captured in 2019

© Alamy/Collection Christophel

© Alamy/Lifestyle pictures

Right top: Cooper leaves his home and children behind on a quest to save humanity

Right bottom: The *Interstellar* astronauts trek across the surface of

x4 images © Alamy/AF archive

CONTACT

RELEASED: 1997 **DIRECTOR:** Robert Zemeckis
CAST: Jodie Foster, Matthew McConaughey and Tom Skerritt

Contact also uses a bedrock of hard science on which to build an emotional and spiritual drama. In this case it's the SETI program – the Search for Extraterrestrial Intelligence. It's an area that has inspired some frankly laughable movies over the years, but *Contact* takes the endeavour seriously. That's not surprising considering it was written by none other than Carl Sagan, whose book *The Demon-Haunted World* is still one of the great touchstones of rational scientific writing. Sagan first pitched his story of an astronomer who becomes the first human to converse with alien life way back in 1979, but it took almost 20 years to come to fruition, with Foster in the lead role combing the skies for radio signals as a way of coping with the death of her father.

It's the way that SETI is portrayed that earns it a place on our list. Sagan takes care to not only work out what might have prompted a distant star system to reach out to us – Hitler's speech from the 1936 Olympics, the first broadcast signal powerful enough to leave Earth, have time to reach a distant star and get a reply. But the nature of that reply is also grounded in the plausible, with the aliens using the value of hydrogen's atomic weight multiplied by pi to reveal the frequency to receive a pattern of repeating prime numbers, all mathematical elements that would identify a signal as intelligent.

DID YOU KNOW?

Throughout the movie, a remark is made by several characters that if humans were the only life in the universe it would be "a terrible waste of space". This remark is a reference to a statement by Scottish historian and essayist Thomas Carlyle when discussing the possibility of worlds beyond our own: "A sad spectacle. If they be inhabited, what a scope for misery and folly. If they be not inhabited, what a waste of space."

© Alamy/Collection Christophel

DID YOU KNOW?

Early in pre-production, Thorne laid down two ground rules. One, nothing would go against established physical laws, and two, that wild speculations would spring from the science and not the creative mind of the screenwriter. Director Christopher Nolan accepted these terms, though it didn't prevent clashes between the two. Thorne apparently spent two weeks talking Nolan out of the concept of having the characters travel faster than the speed of light.

© Alamy/PictureLux / The Hollywood Archive

Below: Jodie Foster plays Dr Ellie Arroway in *Contact*

APOLLO 13

RELEASED: 1995 **DIRECTOR:** Ron Howard
CAST: Tom Hanks, Bill Paxton and Kevin Bacon

While the likes of *Interstellar* and *Contact* take their cues from theoretical deep-space physics, director Ron Howard needed no such leaps for his 1995 hit *Apollo 13*. He had real life to draw from in the shape of NASA's ill-fated third moonshot mission of 1970. When an oxygen tank failed two days into the mission, the Moon landing was aborted, and all attention turned to getting astronauts Jim Lovell, Jack Swigert and Fred Haise home safely as their life-support systems shut down.

In the movie that trio was played by Tom Hanks, Kevin Bacon and Bill Paxton, with Ed Harris as their flight commander on the ground and Gary Sinise as Ken Mattingly, who was forced to drop out of the flight due to illness and instead helps bring his colleagues back to Earth. The film is tight, claustrophobic and brings its scientific focus right down to a granular level. The core of the film is basically an intricate engineering problem, which gets solved through trial and error against a life-or-death deadline as re-entry approaches. Most impressive is how the movie goes out of its way to illustrate just how bare-bones those early spaceflights really were, with the amps needed to restart their Command Module systems reliant on even a single light bulb being unscrewed.

The dashboard of the average secondhand car today is magnitudes more powerful than a vehicle that actually ferried humans into space and back. And by dramatising that remarkable truth in human terms, Howard gave us one of the purest depictions of applied science in cinema history.

© Alamy

Above: NASA astronaut Drew Feustel and Matt Damon during an interview

© Alamy/Moviestore Collection Ltd

Left: Tom Hanks, Bill Paxton and Kevin Bacon playing Jim Lovell, Fred Haise and Jack Swigert

"THE MOVIE GOES OUT OF ITS WAY TO ILLUSTRATE JUST HOW BAREBONES THOSE EARLY SPACEFLIGHTS REALLY WERE"

© Alamy/ AA Film Archive

DID YOU KNOW?

Gerald D. Griffin, former director of the NASA Johnson Space Center, was a technical advisor for *Apollo 13*. He was also a technical advisor for *Contact* and *Deep Impact*, where he also had a small acting role. Throughout his career with NASA, Griffin held many positions including flight director in Mission Control for all of the Apollo manned missions and lead flight director for three lunar landing missions: Apollo 12, 15 and 17. He was also part of the team of flight controllers who were responsible for ensuring the ill-fated Apollo 13 mission made it back safely.

THE MARTIAN

RELEASED: 2015 **DIRECTOR:** Ridley Scott
CAST: Matt Damon, Jessica Chastain and Kristen Wiig

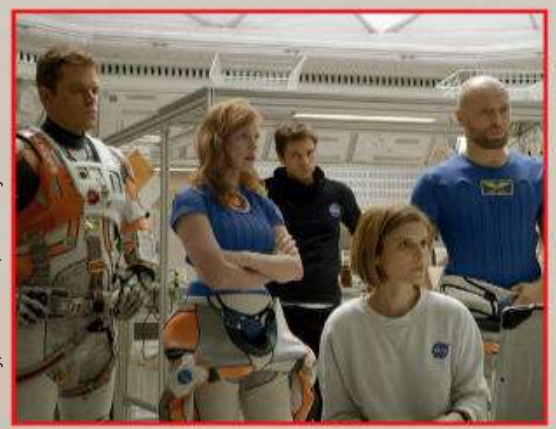
The Martian succeeds by combining the wider considerations of space travel, as seen in *Interstellar*, with the nuts and bolts of immediate problem solving that drove *Apollo 13*... the best of both worlds, you might say. Based on Andy Weir's novel and set in the year 2035, the film stars Matt Damon as Mark Watney, a botanist left stranded on Mars after an accident during a manned research mission to the Red Planet. The scientific ramifications of his predicament are immediately made clear: even if his colleagues, already on their way home, knew he was still alive, it would take months for them to turn around. And the next manned mission isn't for another four years and will land 2,000 kilometres from his location. Whatever happens, he's living alone on an alien world for the foreseeable future.

Everything from how Earth discovers Watney is still alive to the practicalities of mounting a rescue mission millions of miles away and the day-to-day questions of how Watney will eat, breathe and live is founded in science. The film is essentially a series of dramatised experiments, covering the core disciplines of physics, biology and chemistry, with one man's life in the balance. Throughout it all, scientists are the main characters, a diverse and rounded group that nimbly avoids all the usual science nerd stereotypes.

The result is a thrilling and constantly entertaining movie that doesn't just use science to advance the plot, but tells a story where the science is the plot. Such a thing is a rarity and should be cherished when it happens.

Left: *The Martian* sees Matt Damon as Mark Watney, a botanist left behind on Mars

Below: Damon, Chastain, Sebastian Stan, Kate Mara and Aksel Hennie portray members of the fateful mission



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DID YOU KNOW?

The majority of *The Martian* was filmed on indoor sets in Budapest, Hungary, but many of the exterior shots of Mars were filmed in Wadi Rum, also known as the Valley of the Moon, in southern Jordan. This same location was used for certain shots in the epic Hollywood classic *Lawrence of Arabia*. To make the desert region look more like Mars, director Ridley Scott said he later changed the colour of the sky – because Mars has almost no atmosphere, it wouldn't have blue skies like Earth – and some effects were applied to make the landscape look slightly more red.

Focus on

NEW SATELLITE CONSTELLATION TO TRACK GREENHOUSE GAS EMISSIONS

The new mission will monitor human-made emissions from orbit

Reported by Tereza Pultarova

A new mission will track human-made emissions of greenhouse gases from space to help keep the world on track to meet climate change mitigation targets. The new mission, announced by the European Space Agency (ESA) and the European Union's Earth-monitoring program Copernicus during the 2021 UN Climate Change Conference in Glasgow on 2 November, will rely on a dedicated constellation of satellites.

The constellation, called anthropogenic CO_2 emissions Monitoring and Verification Support Capacity (CO2MVS), is currently being developed by the ESA and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). Once in orbit, the satellites will measure concentrations of the two most common greenhouse gases, carbon dioxide and methane, in unprecedented detail and in near real time.

Carbon dioxide, which is released during fossil fuel combustion and in agriculture, is the most common climate-warming gas, accounting for nearly 80 per cent of all greenhouse gas emissions. Methane, while only accounting for about 16 per cent of global greenhouse gas emissions, is 80 times more potent in warming up Earth's atmosphere than carbon dioxide, and therefore also a cause for concern.

The new CO2MVS constellation should be up and running by 2026, in time to help the world review its progress in curbing greenhouse gas emissions as required by the Paris Agreement, the international treaty negotiated during the 2015 UN Climate Change Conference held in the French capital. That agreement requires nations to take stock of their progress every five years to ensure that countries are on track to meet their greenhouse gas reduction targets.

The first such analysis is expected to conclude by 2023; the new constellation could be part of the second, due to be completed in 2028. Copernicus representatives said that the new satellite tool will be "game-changing", allowing climate researchers to see individual sources of

© NPL

Left: The constellation will be able to detect sources of emissions

greenhouse gas emissions, such as power plants and fossil fuel production sites.

Other satellites currently measure changes in atmospheric concentrations of carbon dioxide. However, these are mainly related to natural variations in the carbon cycle and cannot spot individual industrial sources. Canadian company GHGSat is currently using three microsatellites to detect sources of methane emissions. The project, which launched its first satellite in 2016, has successfully measured methane leaks from mining operations and offshore oil platforms as well as waste-disposal sites. But the new European constellation is designed to provide broader coverage, sharper detail and higher accuracy compared to what's currently available.

The data will be integrated into computer models of Earth's atmosphere and biosphere that are already being used by the Copernicus Atmosphere Monitoring Service (CAMS). The CO2MVS constellation will be administered by the European Centre for Medium-Range Weather Forecasts (ECMWF) on behalf of the European Commission, with funding from the European Union.

"Since the start of the Industrial Revolution, we have seen carbon dioxide levels increase faster than ever before, and there is an increasing urgency to take real steps to make very significant emission reductions," said Richard Engelen, deputy director of CAMS. "By providing globally consistent and high-quality data on anthropogenic emissions, we can support policymakers with this enormous challenge."

Below: An artist's rendering of one of the craft that will form the new constellation

"THE NEW EUROPEAN CONSTELLATION IS DESIGNED TO PROVIDE BROADER COVERAGE, SHARPER DETAIL AND HIGHER ACCURACY"

© ESA

NASA's DART mission will conduct an asteroid redirection test

© NASA

USER MANUAL

DART MISSION

THE SPECS

Planned launch: 24 November 2021

Launch rocket: SpaceX Falcon 9

Target: Didymos and Dimorphos

Operators: NASA

Orbital inclination: Halo orbit

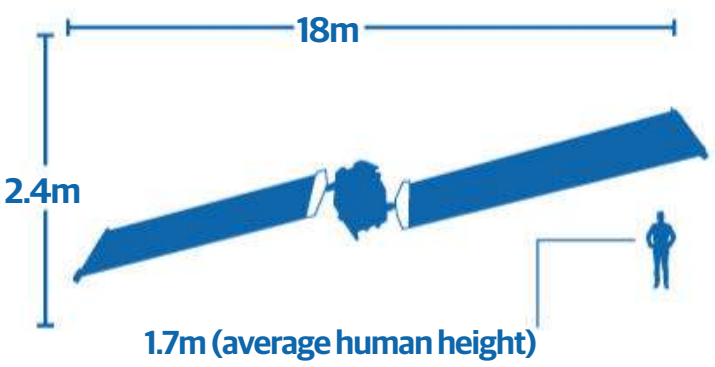
Estimated cost:

$313.9 million (£227.9 million)

DART impact:

26 September to 2 October 2022

Distance from Earth: 11 million kilometres (6.8 million miles)



NASA's Double Asteroid Redirection Test (DART) is an ambitious project designed to test a method of deflecting an asteroid for the purpose of planetary defence using the kinetic impactor technique. DART is to launch between 24 November 2021 and 12 February 2022, though the delayed launch window won't impact the spacecraft's scheduled arrival time at its target in late September 2022. DART's target is a binary near-Earth asteroid: Didymos and its moonlet Dimorphos. DART is the first planetary defence mission to test asteroid deflection methods.

DART will deliberately impact the moonlet Dimorphos at speeds of 6.6 kilometres (4.1 miles) per second. The impact should cause the moonlet's orbital speed to change by a fraction of a percent. This slight shift should be enough to change its orbital period by several minutes. The change in Dimorphos' orbit around Didymos will be observed and measured by telescopes on Earth in order to see whether the mission has been a success. Though the threat from asteroid impacts is small, it's a threat to life on Earth nonetheless, and something we should be prepared for. We only need to look at past impact events, such as the massive Chicxulub asteroid impact that is credited with the extinction of the dinosaurs 65 million years ago, to see the catastrophic effects an impact can have on life on Earth.

Early detection of near-Earth asteroids is the first step in planetary defence. Approximately 30 new discoveries of near-Earth asteroids are made each week, and at the start of 2019 there were more than 19,000 known near-Earth asteroids. DART will be the first mission to test an asteroid deflection technique.

The DART mission is a joint endeavour by NASA and Johns Hopkins University's Applied Physics Laboratory (APL). The mission's target is the binary asteroid system Didymos, which means 'twin' in Greek. The system consists of a near-Earth asteroid, 65803 Didymos, measuring 780 metres (2,560 feet) across and its moonlet Dimorphos, which measures 160 metres (525 feet) across.

Though the pair are not a threat to Earth, they are perfect candidates for the DART mission since Dimorphos is around the same size as an asteroid that could pose the most likely threat to Earth if it were on a collision course with the planet. Their orbit around the Sun is also close enough to Earth for ground-based telescopes to observe and measure any differences after the collision.

"DART IS THE FIRST PLANETARY DEFENCE MISSION TO TEST ASTEROID DEFLECTION METHODS"

ANATOMY OF DART

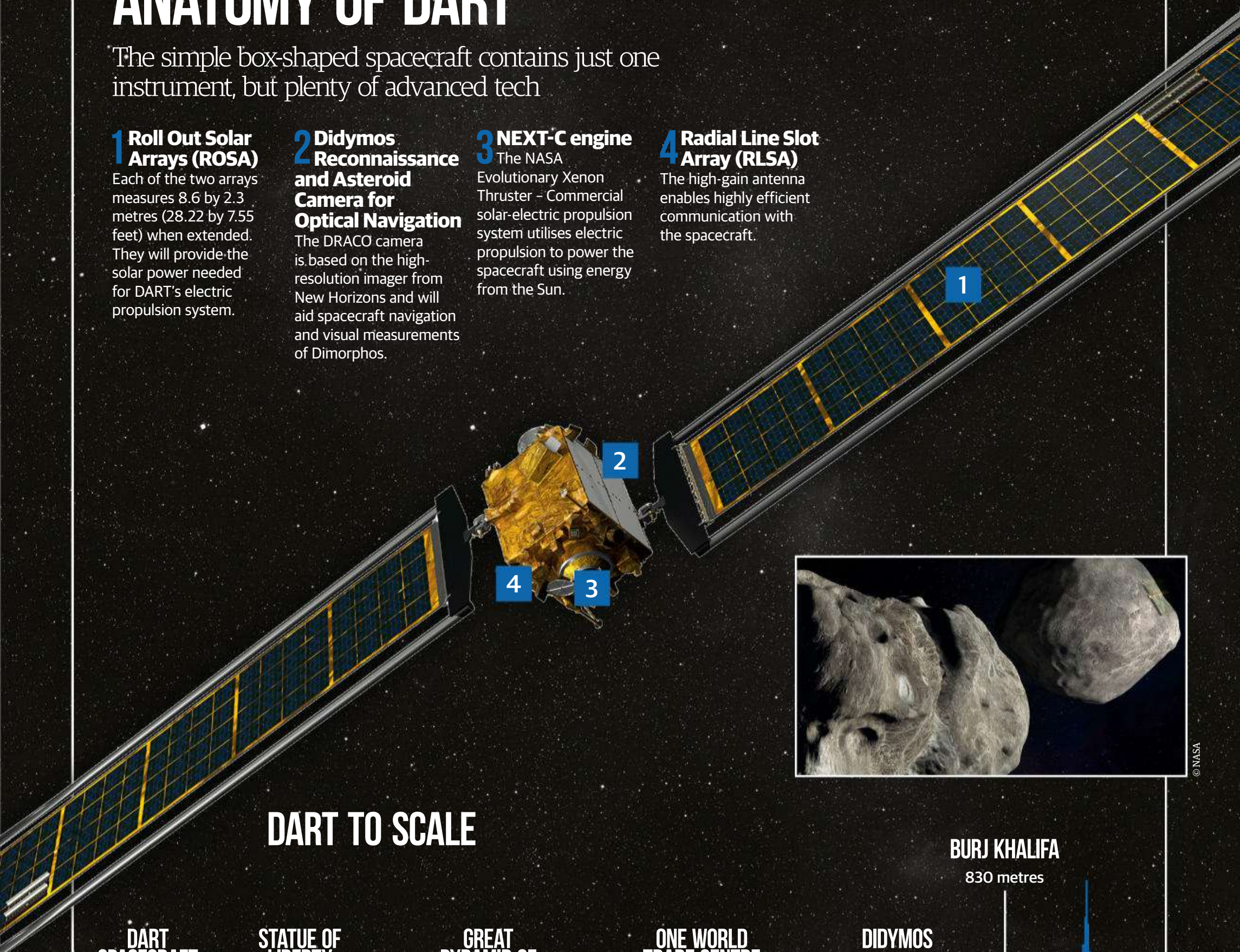
The simple box-shaped spacecraft contains just one instrument, but plenty of advanced tech

1 Roll Out Solar Arrays (ROSA)
Each of the two arrays measures 8.6 by 2.3 metres (28.22 by 7.55 feet) when extended. They will provide the solar power needed for DART's electric propulsion system.

2 Didymos Reconnaissance and Asteroid Camera for Optical Navigation
The DRACO camera is based on the high-resolution imager from New Horizons and will aid spacecraft navigation and visual measurements of Dimorphos.

3 NEXT-C engine
The NASA Evolutionary Xenon Thruster – Commercial solar-electric propulsion system utilises electric propulsion to power the spacecraft using energy from the Sun.

4 Radial Line Slot Array (RLSA)
The high-gain antenna enables highly efficient communication with the spacecraft.



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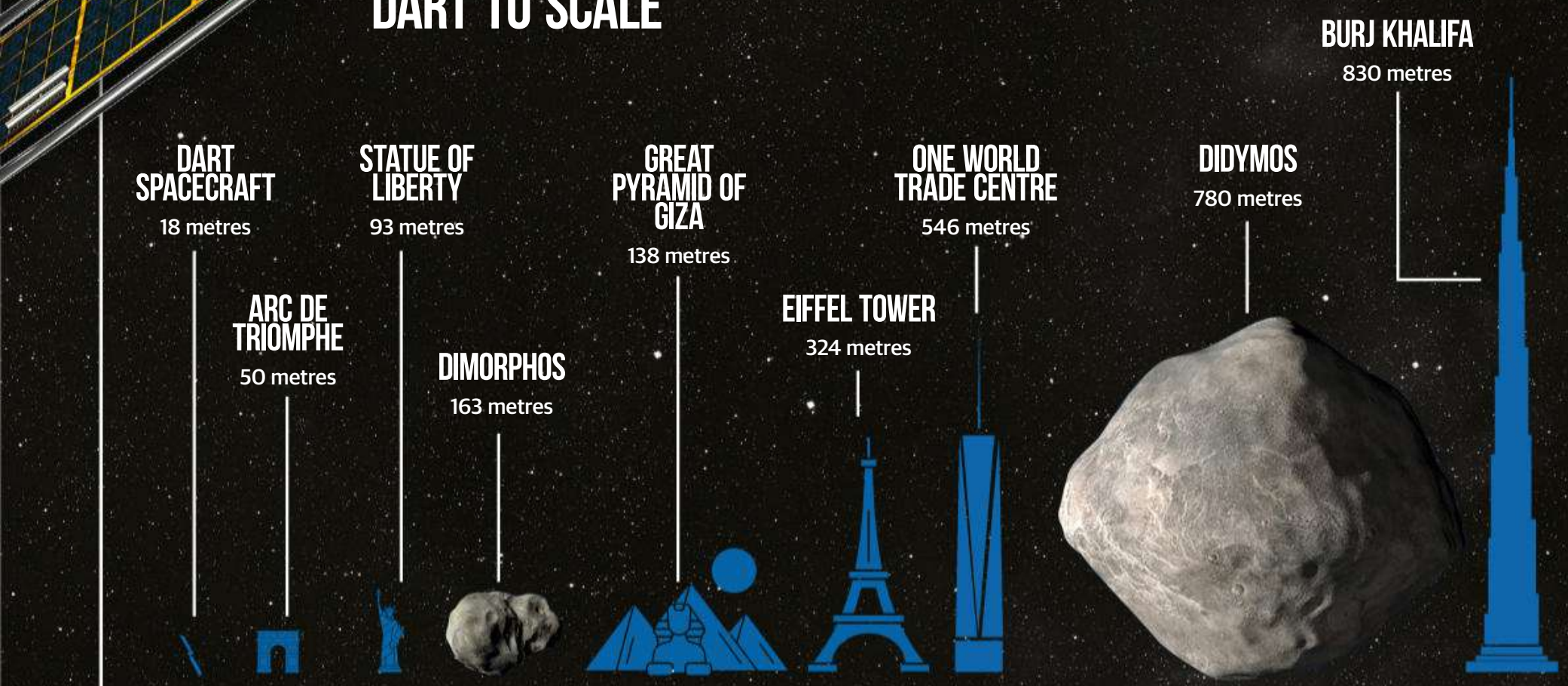
DART TO SCALE



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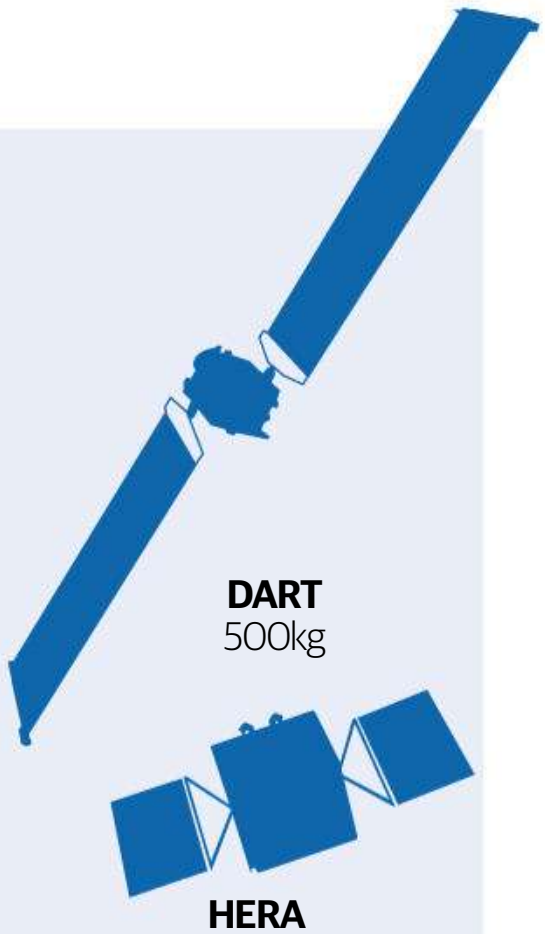
HEAD TO HEAD

DART VS HERA

The European Space Agency's (ESA) Hera will conduct post-impact investigations of DART's collision. The spacecraft is planned to launch in 2024 and reach the Didymos system in 2026. The ESA's Hera spacecraft will be joined by two cubesats. Together they will carry out surveys of both Didymos and Dimorphos, paying particular attention to the crater left by DART's impact. The Hera mission also aims to determine a precise mass of Dimorphos.

Though the two missions are designed and operated independently, together they will advance our understanding of planetary defence technologies. Members from both missions are part of an international collaboration known as Asteroid Impact and Deflection Assessment (AIDA), a large international collaboration between the ESA, German Aerospace Center, the Observatoire de la Côte d'Azur, NASA and APL.



DART is a simple spacecraft. The box-shaped main vehicle measures roughly 1.2 by 1.3 by 1.3 metres (3.9 by 4.3 by 4.3 feet) – about the size of a refrigerator. Each of the two large solar arrays is 8.5 metres (27.9 feet) long when fully deployed. The DART spacecraft contains just one instrument, the Didymos Reconnaissance and Asteroid Camera for Optical Navigation (DRACO). It turns out that if your primary goal is to smash into an asteroid, you don't need to take a lot with you.

Once DART launches on its SpaceX Falcon 9, it will deploy its Roll Out Solar Arrays (ROSA) to power itself for the journey to Didymos. Scientists tested the ROSA arrays on board the International Space Station in June 2017, and they were deemed suitable to provide the power required to support DART's electric propulsion system. In fact, NASA is adding larger versions of the ROSA arrays to the space station's own power grid. The DART spacecraft will use the next-generation, fuel-

HOW TO DEFEND EARTH AGAINST AN ASTEROID

1 Find the asteroid
Ground and space-based telescopes are used to identify near-Earth objects (NEOs) that could pose a threat when entering Earth's neighbourhood.

2 Track the asteroid
When an NEO is detected, scientists map its orbit and make repeated observations to assess whether it's on a collision course with Earth.

3 Characterise the asteroid
Scientists then characterise the asteroid to determine orbit trajectory, size, shape, mass and composition to better understand how to deflect it.

4 Deflect the asteroid
There are three main techniques to deflect an asteroid: use gravity to pull the asteroid off course, smash a spacecraft into the asteroid or use lasers to vaporise the asteroid.

5 Global coordination
An impact would affect the world, and needs a cohesive worldwide response effort. Planetary defence requires advanced coordination and education of NEO threats.

efficient NASA Evolutionary Xenon Thruster – Commercial (NEXT-C) solar-electric propulsion system as part of its in-space propulsion.

DART will be guided to its target Dimorphos by sophisticated autonomous navigation software. It's no easy feat to locate a target that's 160 metres (525 feet) in diameter and 11 million kilometres (6.8 million miles) from Earth. The navigation software is designed to identify both Didymos and Dimorphos and distinguish between the two so that DART can be directed to the smaller body, Dimorphos, for its impactful mission.

As the spacecraft approaches its target, DRACO, the onboard high-resolution camera, will help navigate the DART spacecraft and take measurements of the target asteroid, including the size and shape of Dimorphos.

But the DART spacecraft won't be making its journey to the near-Earth asteroid binary alone. The spacecraft will be joined by LICIACube, or the Light Italian Cubesat for Imaging Asteroids. LICIACube is a CubeSat contributed by the Italian Space Agency and built by Italian aerospace engineering company Argotec. The LICIACube weighs just 14 kilograms and measures roughly the length of an adult's hand and forearm. The little CubeSat has a very important job, and will be deployed by DART around ten days before the spacecraft will impact Dimorphos. LICIACube will then hang back and witness the impact, capturing images of the collision to help researchers verify the efficacy of the impact.

"DART WILL BE GUIDED TO ITS TARGET DIMORPHOS BY SOPHISTICATED AUTONOMOUS NAVIGATION SOFTWARE"

DART BY NUMBERS

19,000

Number of near-Earth asteroid discoveries

8.6M

Length of each of DART's ROSA arrays

1.18KM

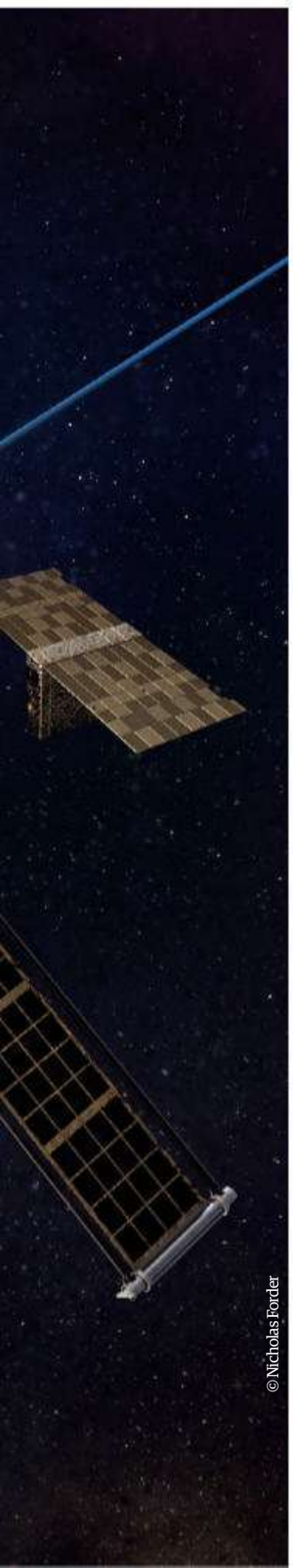
Distance between Didymos and Dimorphos

11.92

Orbital period of Dimorphos in hours

23 JUNE 2020

The asteroid moonlet Dimorphos was formally named by the International Astronomical Association



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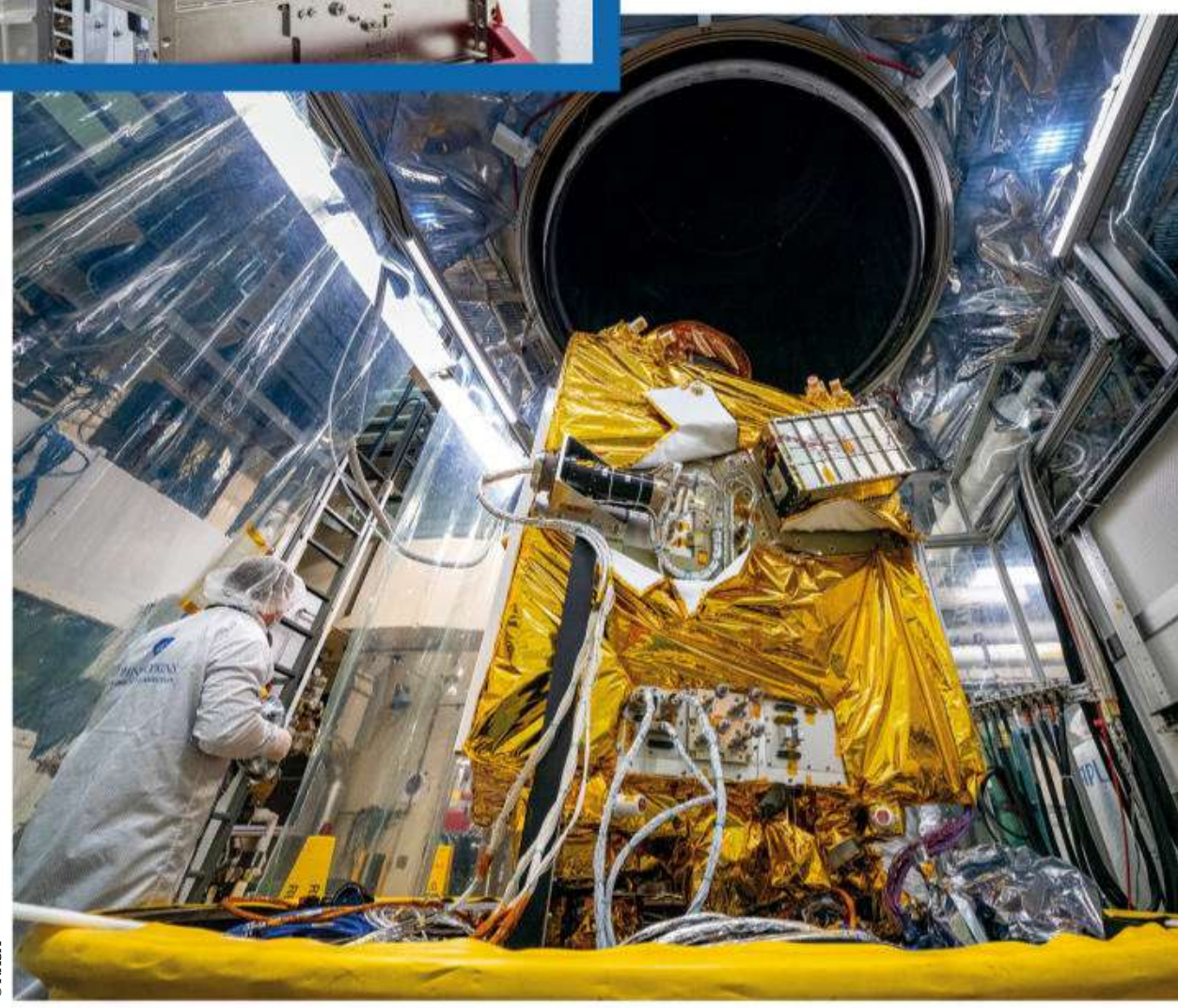
TOP TECH

ROLL OUT SOLAR ARRAYS (ROSA)

The DART spacecraft's arrays are crucial for enabling the spacecraft to reach its target Dimorphos. The impressive solar arrays are light and compact, and will slowly unfurl to reach 8.5 metres (27.9 feet) in length – about the length of a bus. The arrays were first tested on the International Space Station in 2017, and DART will be the first spacecraft to fly the new arrays, paving the way for future missions.

© NASA

Above: LICIACube will witness DART's impact with Dimorphos. In this image, a team of engineers inspects the LICIACube at the Johns Hopkins Applied Physics Laboratory



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Right: DART may launch very soon, but has a backup launch window in case it's not quite ready

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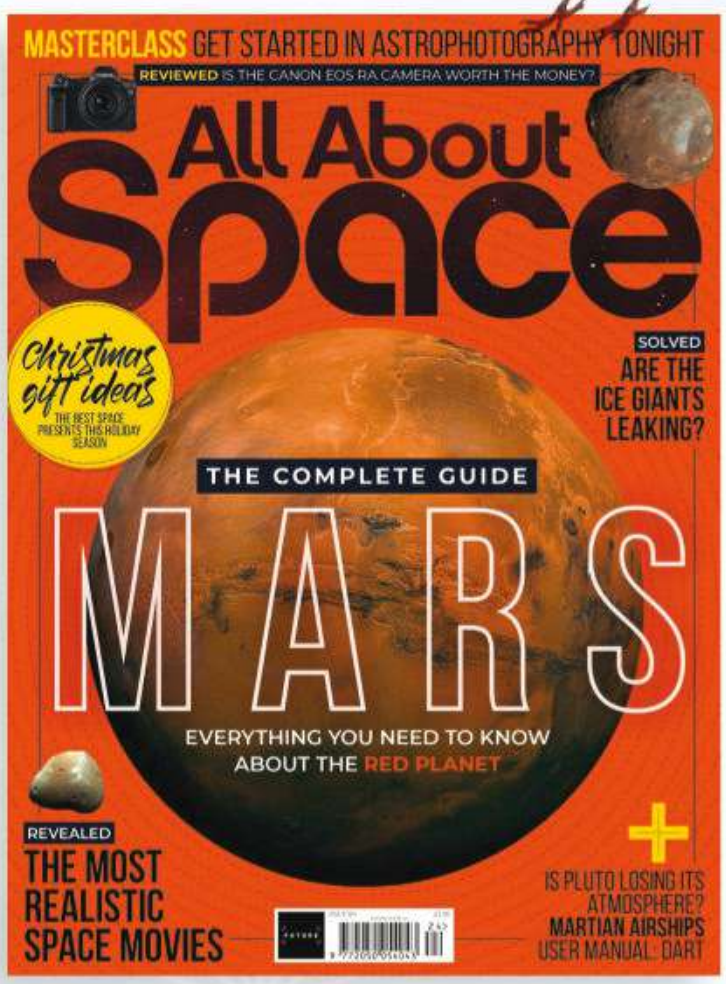
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Focus on

LARGEST COMET EVER DISCOVERED IS HEADED OUR WAY

Bernardinelli-Bernstein is making its trip towards the Sun

Reported by Brandon Specktor

An enormous comet – possibly the largest one ever detected – is barrelling towards the inner Solar System with an estimated arrival time of ten years from now.

The comet, known as Bernardinelli-Bernstein, or officially C/2014 UN271, is at least 100 kilometres (62 miles) across – about 1,000 times more massive than a typical comet. It's so large that astronomers previously mistook it for a dwarf planet.

A closer analysis of the object revealed that it was moving rapidly through the Oort Cloud – a vast scrap yard of icy rocks billions of miles from Earth. The object appeared to be headed our way, and it even had a glowing tail, or 'coma', behind it – a clear indication of an icy comet approaching the relatively warm inner Solar System. Now researchers have studied the massive comet in more detail, and they have new estimates about its journey towards the Sun.

For starters, the enormous rock poses no threat to Earth. Right now Bernardinelli-Bernstein (BB) is cruising through the Oort Cloud at about 29 times the distance between Earth and the Sun, or 29 astronomical units (AU). The comet's closest approach to Earth will occur some time in the year 2031, when scientists predict the comet will swoop within 10.97 AU of the Sun – putting it just outside of Saturn's orbit.

While that's far enough from Earth that observers won't be able to see the comet without telescopes, it's considerably closer than the rock's last visit to our part of the Solar System. After modelling the comet's trajectory, new research calculated that BB made its last approach 3.5 million years ago, coming within 18 AU of the Sun. Since then, the comet travelled as far as 40,000 AU away, deep into the mysterious Oort Cloud. "We conclude that BB is a 'new' comet in the sense that there is no evidence for [a] previous approach closer than 18 AU," the researchers wrote; in other words, humans have never laid eyes on it before.

We owe our current view of the large, distant comet to the Dark Energy Survey (DES) – a project to study the expansion of the universe

"RESEARCHERS HAVE PLENTY OF TIME TO STUDY THE MASSIVE COMET AS IT SOARS EVER CLOSER TO EARTH OVER THE NEXT DECADE"

Right: The object was originally thought to be a dwarf planet because of its size

© NOIRLab

which ran between August 2013 and January 2019. During the survey, astronomers mapped 300 million galaxies in the southern sky, discovering more than 800 previously unknown objects beyond the orbit of Neptune. The BB comet was one of those objects.

Researchers have plenty of time to study the massive comet as it soars ever closer to Earth over the next decade. Getting a closer look at the rock could help scientists understand a bit more about the chemical composition of the early Solar System, as comets from deep in the Oort Cloud are thought to be relatively unchanged since they were booted away from the Sun billions of years ago. With millions of years separating the comet's next close approach from its following one, it'll be a once-in-a-lifetime brush with the early Solar System.

14

INCREDIBLE GALAXIES

1 PRETTY PINWHEEL

MESSIER 83

Messier 83 is a large, photogenic spiral galaxy with a bar-shaped centre. It sits 15 million light years away in the constellation of Hydra. Messier 83 is weird in a couple of ways. First, it appears to have a double nucleus at its centre - perhaps the mark of two supermassive black holes holding the galaxy together, or perhaps the effect of a lopsided disc of stars orbiting a single central black hole. Secondly, Messier 83 is a supernova supersite. Astronomers have directly observed six of these stellar explosions in the galaxy, along with remnants of 300 more. This puts Messier 83 in second place for supernovae – only the galaxy NGC 6946 has produced more observable stellar explosions, with nine.

© NASA, ESA, the Hubble Heritage

2 TWO HEARTS

NGC 7674

Most galaxies are likely to be anchored by a supermassive black hole at their centre. A few, however, contain not one, but two black holes. One of these is NGC 7674, a spiral galaxy whose centre boasts a pair of black holes a mere light year apart. The galaxy, 380 million light years from Earth, probably collected the spare black hole during a collision and merger with another galaxy. The only other galaxy known to have two black holes at its heart is a supermassive galaxy called 4C +37.11.

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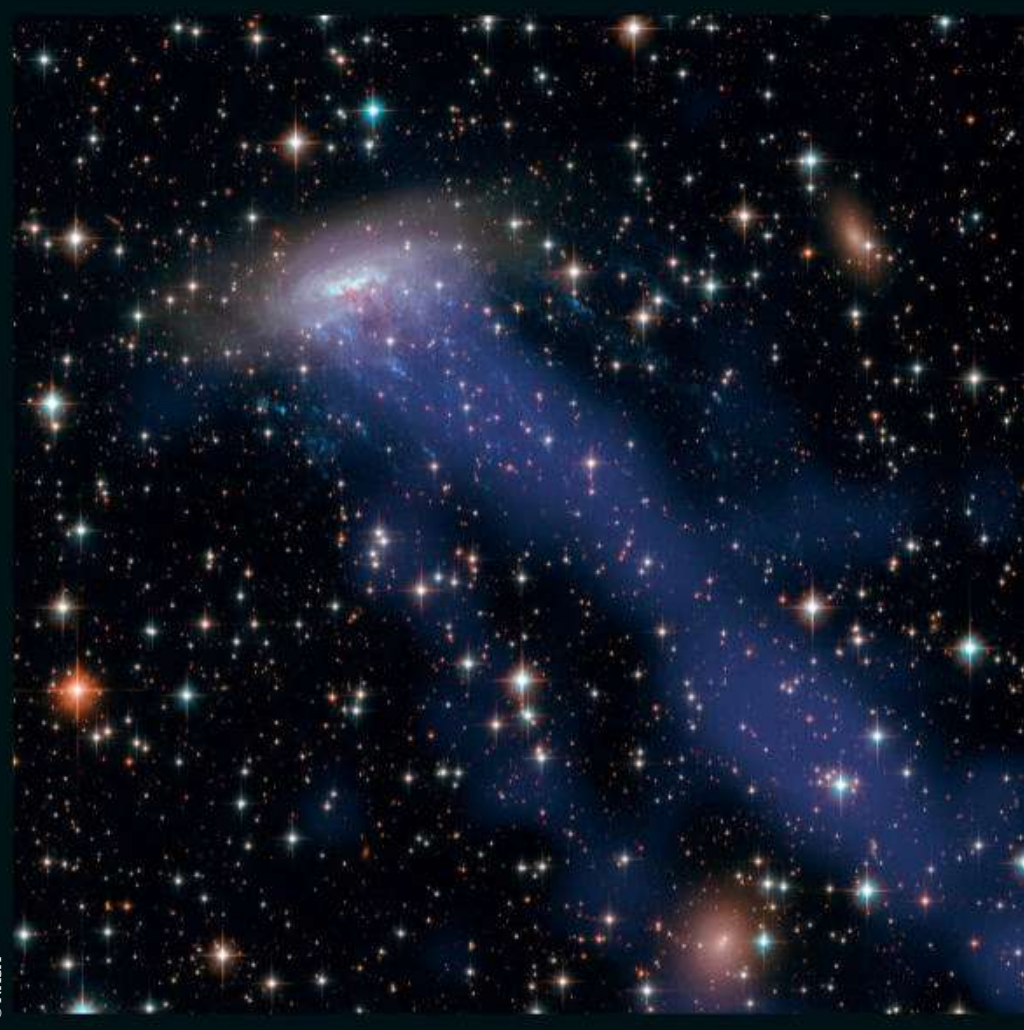
OUT BEYOND OUR MILKY WAY THERE ARE GALAXIES SHAPED LIKE JELLYFISH, GALAXIES THAT CONSUME OTHERS AND GALAXIES THAT SEEM TO LACK THE DARK MATTER THAT PERVADES THE REST OF THE UNIVERSE

Written by Stephanie Pappas

3 JUST LIKE A JELLYFISH

ESO 137-001

Located in the constellation of Triangulum Australe, ESO 137-001 looks like a jellyfish swimming amid a sea of stars. The galaxy is a barred spiral - together its stars form a spiral shape with a bar-shaped centre - with a twist: streamers of stars that seem to drift like jellyfish tentacles. These stars are forming inside a tail of dust and gas - one invisible to the naked eye - that streams off ESO 137-001. This formation process is a bit of a mystery, as the gases in the tail should be too hot for star formation.



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4 GALAXY IN BLOOM

ESO 381-12

Against the void of space, ESO 381-12 seems to bloom. This galaxy, 270 million light years from Earth, is in the constellation of Centaurus. It's a lenticular galaxy, a hybrid between a spiral galaxy and a stretched-out elliptical galaxy. What makes ESO 381-12 really strange are the uneven, petal-like blooms that ghost outwards from the main galactic body. Astronomers aren't entirely sure what causes these structures, or the clusters of stars that orbit on the galaxy's edges. It's possible that the blooms are shock waves from a relatively recent galactic collision that also provided the galaxy with new fuel for star formation.

5 LUMINOUS THIEF

W2246-0526

Galaxies frequently interact with one another, squeezing their neighbours into new shapes, stealing stars and carrying on with other shenanigans. The brightest known galaxy in the universe is one of these thieves. In 2018, scientists announced that they'd observed the galaxy W2246-0526 sucking up half the mass of three nearby galaxies. Astronomers were able to observe streamers of mass connecting the galaxies – at least as they were more than 12 billion years ago, when that light began its journey towards Earth.

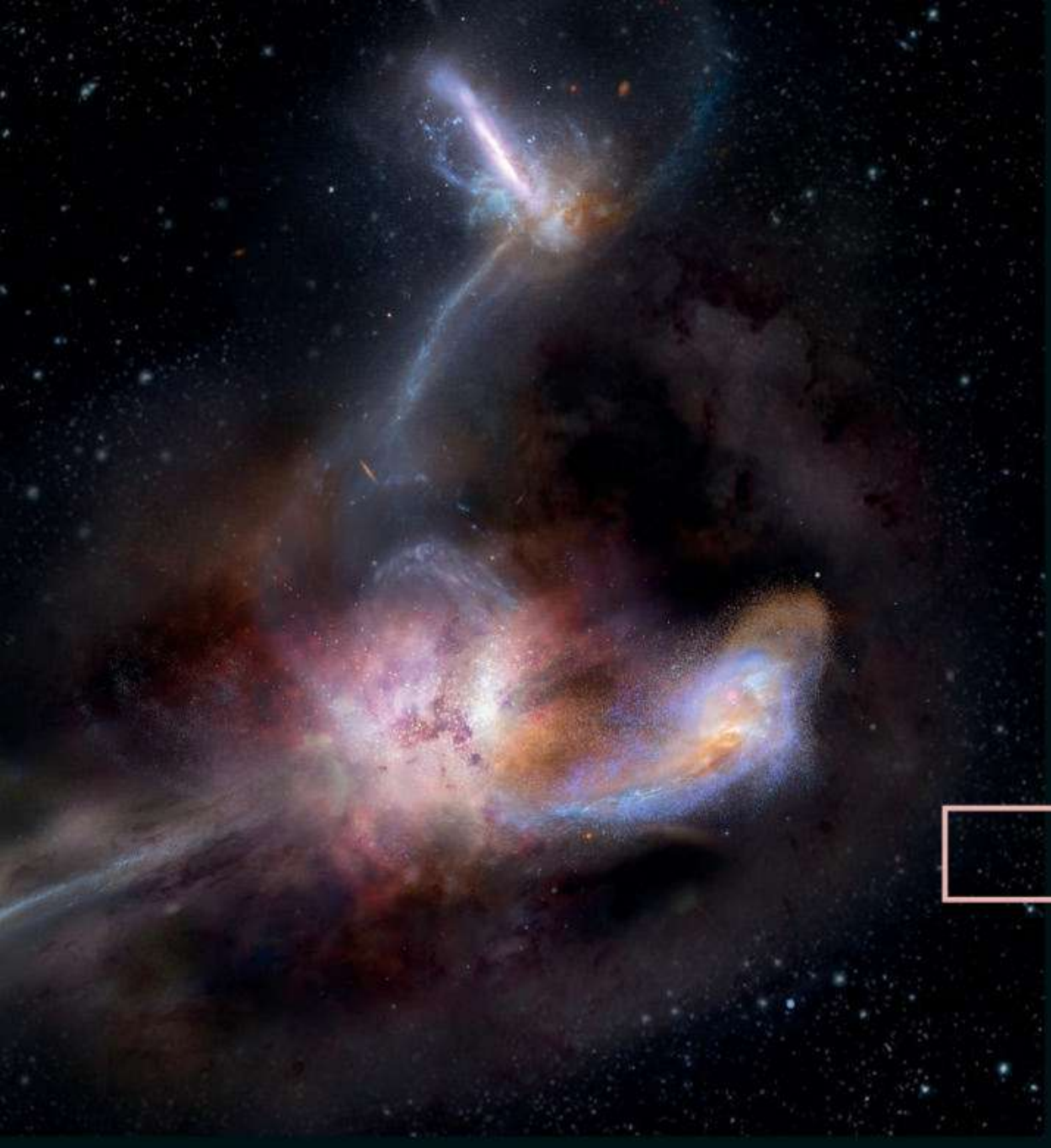
© ALMA

"WHAT MAKES ESO 381-12 REALLY STRANGE ARE THE UNEVEN, PETAL-LIKE BLOOMS THAT GHOST OUTWARDS FROM THE MAIN GALACTIC BODY"

6 THE EYE

IC 2163 & NGC 2207

The disc of spiral galaxy IC 2163 seems to peer out into space with an enormous eye. This eye-shaped feature is actually a huge stream of stars and dust, produced when the smaller IC 2163 brushed against another spiral galaxy, NGC 2207. These 'ocular features' last only a few tens of millions of years – that's a blink of an eye in the life span of a galaxy, so discovering one is a unique opportunity. Researchers found that the gases of the eye race towards the centre of IC 2163 at 100 kilometres (62 miles) per second before crashing like a wave on the shore, becoming more chaotic and slowing as they move towards the centre.



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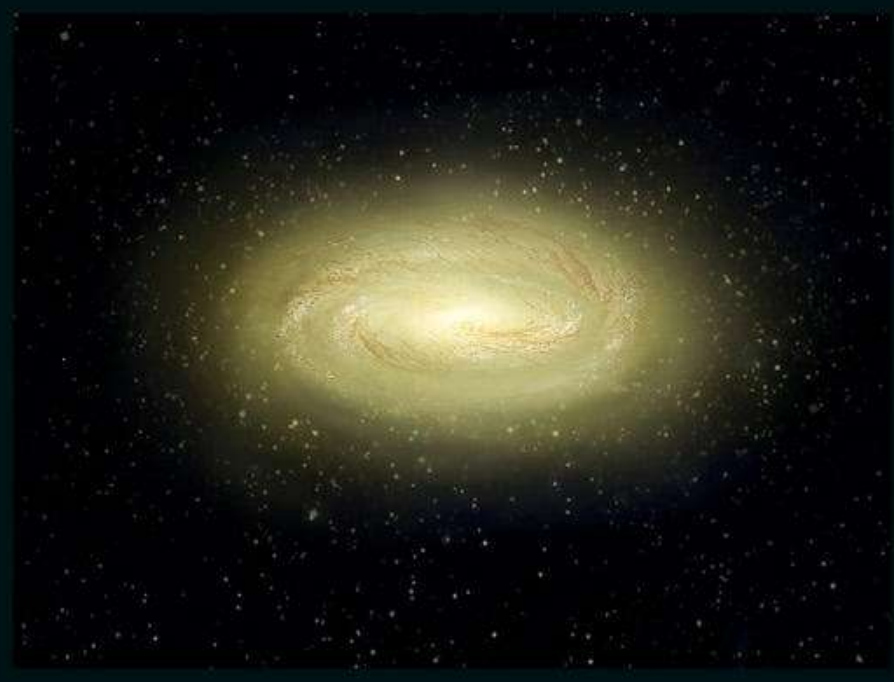

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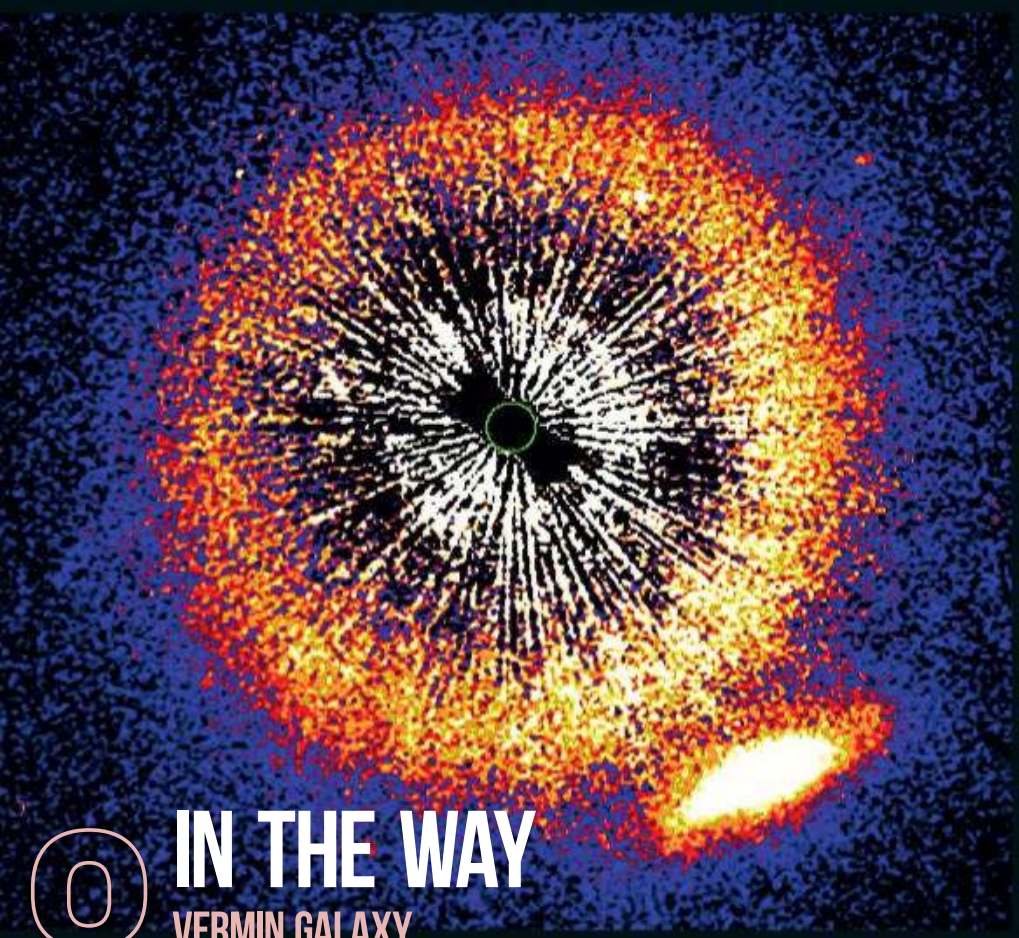
7 ZOMBIE GALAXY

MACS 2129-1

The massive, disc-shaped MACS 2129-1 spins twice as fast as the Milky Way, but it's not nearly as active. Hubble observations of the distant galaxy reveal that it hasn't made stars for some 10 billion years. MACS 2129-1 is what's known as a dead galaxy; stars no longer form there. Its discovery was a head-scratcher. Scientists believed galaxies of this sort formed by merging with smaller galaxies over time, but its stars didn't form from these sorts of explosive mergers – they formed early on in the disc of the original galaxy. The findings suggest that dead galaxies somehow internally rearrange their structure as they age rather than changing shape because they combine with other galaxies.



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8 IN THE WAY

VERMIN GALAXY

This looks more like a psychedelic bit of dandelion puff than a cosmological phenomenon, but this snapshot captured by Hubble has nothing to do with botany. What you're seeing is a galaxy (the smudge at the lower right) beginning to pass behind a star (the sphere). Its called the 'Vermin Galaxy' by some because its light gets in the way of studying the closer star and its system. In 2020, the star fully obscured the galaxy, but scientists can study the spectra of light as the galaxy makes its transit behind the star, perhaps gleaning some information about the debris around the star from the light that makes its way through.

9 COSMIC CANNIBAL

ANDROMEDA

Messier 31, or the Andromeda Galaxy, Earth's largest neighbour, has been devouring smaller galaxies for at least 10 billion years. In another 4.5 billion years, the Andromeda Galaxy and our Milky Way will collide, although it's not yet clear who will devour who in that cosmic pile-up. Unfortunately, earthlings will not be around to see this clash play out, as our Sun is heating up and will likely make life on Earth impossible between about 1 and 5 billion years from now.

Source: wikipedia Commons © Kanwar Singh

© SDSS Collaboration

10 DOOMED GALAXY

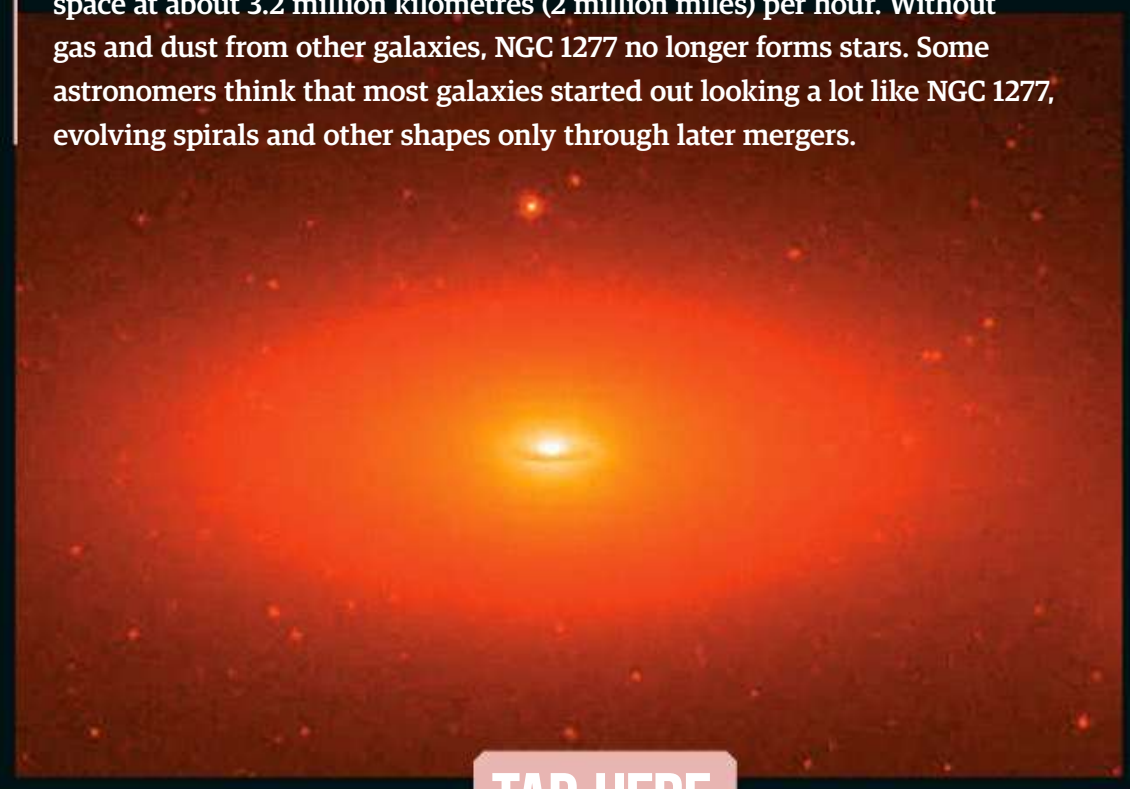
NGC 3359

With possibly the cutest nickname for a galaxy, the 'Little Cub' sits in the constellation of Ursa Major. This dwarf galaxy has been largely dormant since the Big Bang, meaning it might contain molecules unchanged since just moments after the rapid expansion of the universe 13.8 billion years ago. Little Cub is also doomed. It's being consumed by its larger neighbour, a Milky Way-like galaxy called NGC 3359. Still, the opportunity to watch NGC 3359 strip the star-forming gases from the Little Cub is valuable to science; astronomers may be able to measure the signatures of those early universe molecules before they're gone.

11 ARRESTED DEVELOPMENT

NGC 1277

When you're a galaxy, you've got to consume other galaxies or die. NGC 1277 chose the latter. This galaxy, first reported in 2018, is a mere 240 million light years from Earth. It hasn't formed new stars for about 10 billion years. Astronomers believe that NGC 1277 became stunted because it's moving too fast to gobble up other galaxies in its gravitational pull. It's travelling through space at about 3.2 million kilometres (2 million miles) per hour. Without gas and dust from other galaxies, NGC 1277 no longer forms stars. Some astronomers think that most galaxies started out looking a lot like NGC 1277, evolving spirals and other shapes only through later mergers.



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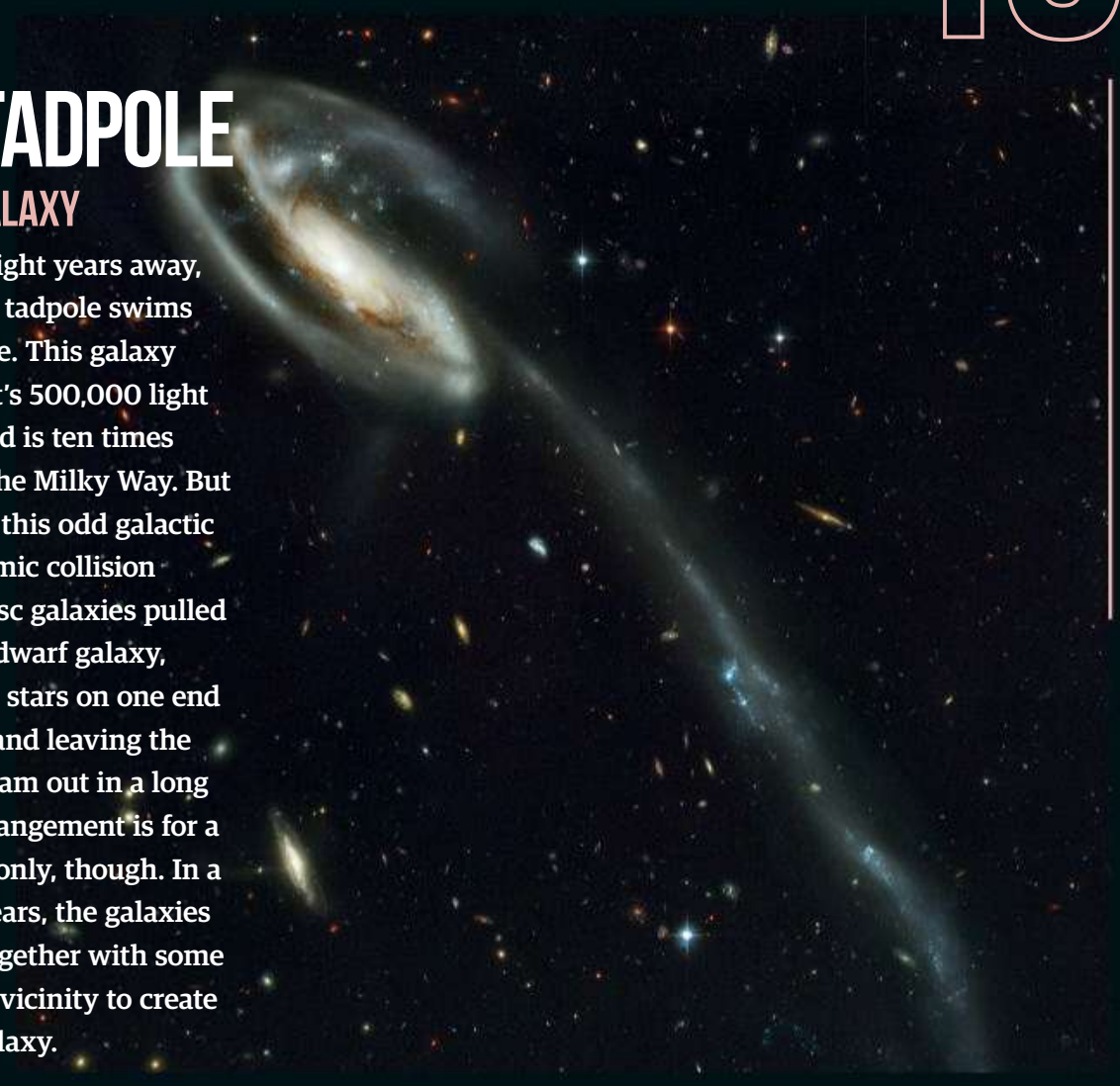
TAP HERE TO PLAY

12 THE TADPOLE

TADPOLE GALAXY

300 million light years away, an enormous tadpole swims through space. This galaxy has a tail that's 500,000 light years long and is ten times longer than the Milky Way. But what created this odd galactic shape? A cosmic collision where two disc galaxies pulled on a smaller dwarf galaxy, clumping the stars on one end into a 'head' and leaving the others to stream out in a long 'tail'. This arrangement is for a limited time only, though. In a few billion years, the galaxies will merge together with some others in the vicinity to create one single galaxy.



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13 MISSING MATTER

NGC 1052-DF2

In 2018, Hubble spied something never seen before: a galaxy with almost no dark matter. Dark matter is a mysterious form of matter that interacts with gravity, but not with light. It makes up more of the total matter in the universe than the matter we can see, so finding a galaxy without any was bizarre, to say the least. A year later, scientific sleuths solved the mystery: NGC 1052-DF2 was not 65 million light years away, as originally believed. It's really only about 42 million light years away. That change in distance completely altered the calculations for the galaxy's mass. Turns out it's a pretty normal galaxy after all, and the universe makes sense again... sort of.

©ESA/Hubble

Source: Wikipedia Commons © Judy Schmidt

"THE LIGHT COMING FROM MESSIER 90 IS SKEWED TOWARDS THE BLUE END OF THE LIGHT SPECTRUM"

14

COMING OUR WAY

MESSIER 90

Most galaxies that scientists observe appear to be moving away from Earth because space is still expanding. But not Messier 90. This spiral galaxy is about 60 million light years away and is moving towards the Milky Way. Astronomers can detect this movement because the light coming from Messier 90 is skewed towards the blue end of the light spectrum. Objects moving away from Earth are redshifted, meaning their light emissions are weighted towards red. Messier 90 is part of a large group of galaxies called the Virgo Cluster. It can be seen from the Northern Hemisphere in May with a telescope or binoculars, sitting between the constellations Virgo and Leo.

Focus on

FRESH MOON ROCKS ARE YOUNGER THAN THE APOLLO SAMPLES

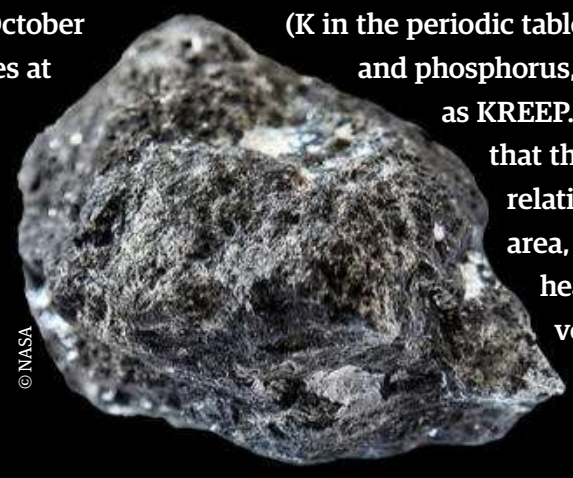
Chang'e 5's delivery has brought new insights about our celestial companion

Reported by Andrew Jones

New analyses of Moon rocks delivered to Earth by China's Chang'e 5 mission confirm that volcanism occurred later than previously known, but also deepen the mysteries surrounding that activity. Chang'e 5 collected 1.73 kilograms of rock from a region called Oceanus Procellarum on the near side of the Moon in December 2020. The mission team targeted this landing area because of its apparent lower density of craters, suggesting it was significantly younger than areas sampled by the Apollo and Soviet Luna missions.

The samples were first processed and catalogued, and the first batch of samples was approved for release in June. Since then, various teams of scientists have been working to learn what the rocks can tell us about the Moon and the history of our Solar System. A paper published in *Science* in early October dated a fragment of the samples at about 1.97 billion years old.

Now a second, published in *Nature* on 19 October, using a similar dating method but on a different sample, gives an age of 2.03 billion years – very close, geologically speaking.



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This pair of dates confirms that volcanic activity was taking place in this area of the Moon around a billion years after the areas sampled by the Apollo and Luna missions had become geologically dead.

That finding tells scientists about the layer of the Moon below the crust. "This means that the mantle had sufficient internal deep-mantle heat 2 billion years ago to continue to melt mantle material and produce extrusive mare basalts," said James W. Head, a professor of geological sciences at Brown University.

Why the mantle beneath this patch of the Moon was still active relatively late in the Moon's history remains a mystery, however. Two additional papers examining the composition of Chang'e 5 samples go against previous thinking on the causes. Existing theories have focused on the heat-producing elements potassium (K in the periodic table), rare Earth elements and phosphorus, together abbreviated as KREEP. Scientists had thought that these materials would be relatively abundant in the area, helping to generate the heat required to make late volcanic activity possible.

But Head's paper and a new study in *Nature* both examined the composition of a portion of the Chang'e 5 samples and found only moderate KREEP content, suggesting the materials are not required for the late volcanism that created these rocks. "The jury is still out on how and why the late-stage volcanism occurred," said Joshua Snape, a planetary scientist at the University of Manchester. "The lack of a KREEP signature that we identified in the *Science* paper is definitely significant, and seems to be confirmed by the studies published in *Nature*," he added, while noting that low KREEP levels cannot yet be wholly ruled out as a factor.

Adding to the mystery is a lack of water found by a team behind a third new paper, which looked at hydrogen isotope compositions in the rocks. A relatively high water content would have helped lower the melting point of the rock, making volcanic activity easier. But this paper finds the rocks are dehydrated, suggesting that abundant water in the mantle can't explain the Moon's youngest confirmed volcanism either. "Perhaps we need to consider whether tidal heating, caused by the stretching and squeezing by gravitational interactions between the Earth, Moon and Sun, could be a larger factor than anticipated," said Snape.

“THE MANTLE HAD SUFFICIENT INTERNAL DEEP-MANTLE HEAT 2 BILLION YEARS AGO TO CONTINUE TO MELT MANTLE MATERIAL”

JAMES W. HEAD

Above: Lunar seas signify past volcanism, where lava flowed across the surface

Left: The new samples vary in size and age

© NASA

MYSTERIES OF THE UNIVERSE

WHY IS GAS MISSING ON URANUS AND NEPTUNE?

We might have an explanation for why the two ice giants don't have the expected levels of ammonia

Reported by David Crookes

Let's get one thing out of the way... ammonia stinks. It's a colourless, irritating gas that occurs naturally, and one whiff of the strong odour can feel sharply suffocating. Even so, it's essential. You'll find it in the air, water and soil here on Earth, and while too much of it can be harmful, it's necessary for the growth of plants and crops. Ammonia is also produced in our bodies by bacteria in our intestines and by our bodies' cells when we process protein. Passed through the liver as waste, it ends up being directed through the kidneys and removed in our urine. So yes, ammonia smells, but it's also fascinating. Found across the universe, it's been the subject of many scientific studies over the years.

In 2016, for instance, there was a major breakthrough when ammonia was discovered in Earth's lowest atmospheric layer for the very first time. Its presence in the troposphere above India and China was believed to be due to livestock farming and fertilisation. It has been helping scientists with climate change models, since ammonia is involved in the creation of clouds and could have a cooling effect.

Astronomers have also known for some time that ammonia is present around Jupiter and Saturn – in fact, they've long believed that the atmospheres of these planets contain the Solar System's largest ammonia reservoirs. NASA's Jupiter-orbiting space probe, Juno, has shown, for example, that Jupiter's equatorial region is particularly rich in ammonia. Saturn also has a pale-yellow hue thanks to ammonia crystals in its upper atmosphere.

TAP HERE TO PLAY

© Tobias Roetsch

MUSHBALLS BY NUMBERS

ONE
Weight in kilograms

TWO-THIRDS
The amount of water contained in a mushball

ONE-THIRD
The amount of ammonia contained in a mushball

10CM
Diameter of a mushball – roughly the size of a baseball

1989
When Voyager 2 flew by Neptune and Uranus

-90°C
Temperature at which mushballs start to form

50KM
The extent the troposphere extends above the surface of Jupiter

FOUR
All of the Solar System's gas giants are thought to experience mushballs

2016
Year Juno began orbiting Jupiter

ZERO
Missions planned for Neptune and Uranus

What has been baffling astronomers, however, is the distinct lack of ammonia higher up in the atmospheres of the Solar System's other giant planets, Uranus and Neptune. According to Tristan Guillot, who works at the Université Côte d'Azur in Nice, France, we would expect these planets to have even higher levels of ammonia in their atmospheres based on the measurements of other compounds. Yet that is not the case.

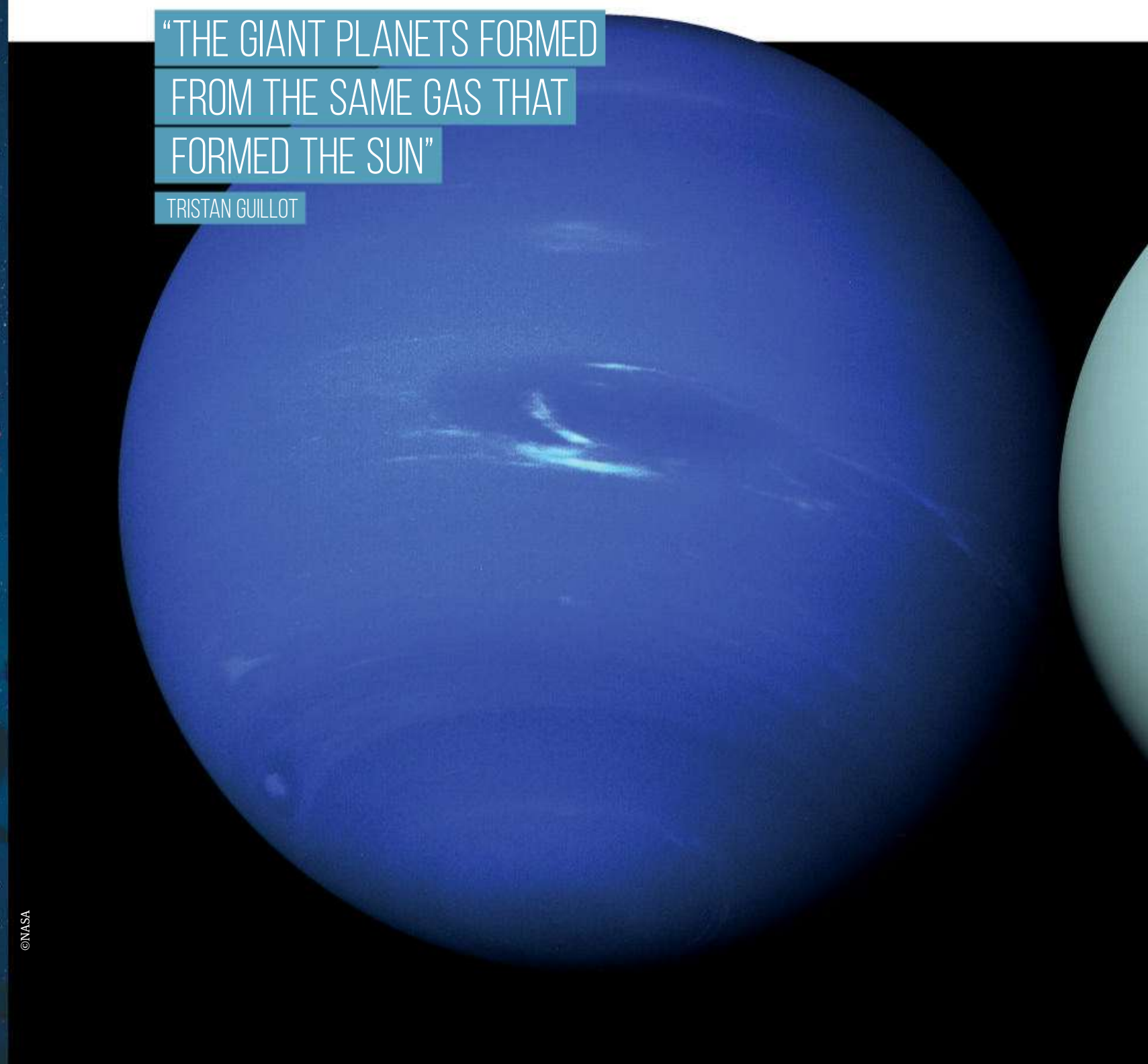
"The giant planets formed from the same gas that formed the Sun, but they acquired comparatively less hydrogen and helium [in gaseous form] and were enriched in materials that were in solid form in the protosolar disc: water ice, methane, ammonia, probably rocks," Guillot tells **All About Space**. "Because the ratio of carbon [in the form of methane] to nitrogen [in the form of ammonia] in Jupiter is the same as in the Sun, and because Uranus and Neptune are farther away than Jupiter where it is colder, we would expect this ratio to remain solar. But it's not what is measured: Uranus and Neptune have very little ammonia in their atmospheres."

Guillot has been keen to discover why this is so, especially since both ice giants have atmospheres rich in other chemical compounds present in the primordial cloud from which the planets formed, such as methane. "This is a crucial issue to understand how giant planets – and therefore the whole Solar System – formed," Guillot explains. "There aren't so many chemical species that we are able to detect in giant planets because most – like rocks – condense deep in the planets and are hidden from view."

For Guillot, unravelling this particular mystery has been something of a long journey. "My mentor, Daniel Gautier, pointed out the issue back when I was doing my PhD in 1992, based on old observations, but the issue has gone largely unnoticed," he says. "Unfortunately, he passed away in 2018." Ironically, it was in 2018 when Guillot's interest was piqued once more, thanks to the study of infrared light from Uranus that was captured by the 8.1-metre (26.6-foot) Gemini North telescope on Hawaii's Mauna Kea. A team led by Professor Patrick Irwin from the University of Oxford's Department of Physics spectroscopically dissected the light, finding hydrogen sulphide in the cloud tops of the gas giant – a compound which smells like rotten eggs.

Below: The great distance to the ice giants makes them harder to study

"THE GIANT PLANETS FORMED FROM THE SAME GAS THAT FORMED THE SUN"
TRISTAN GUILLOT



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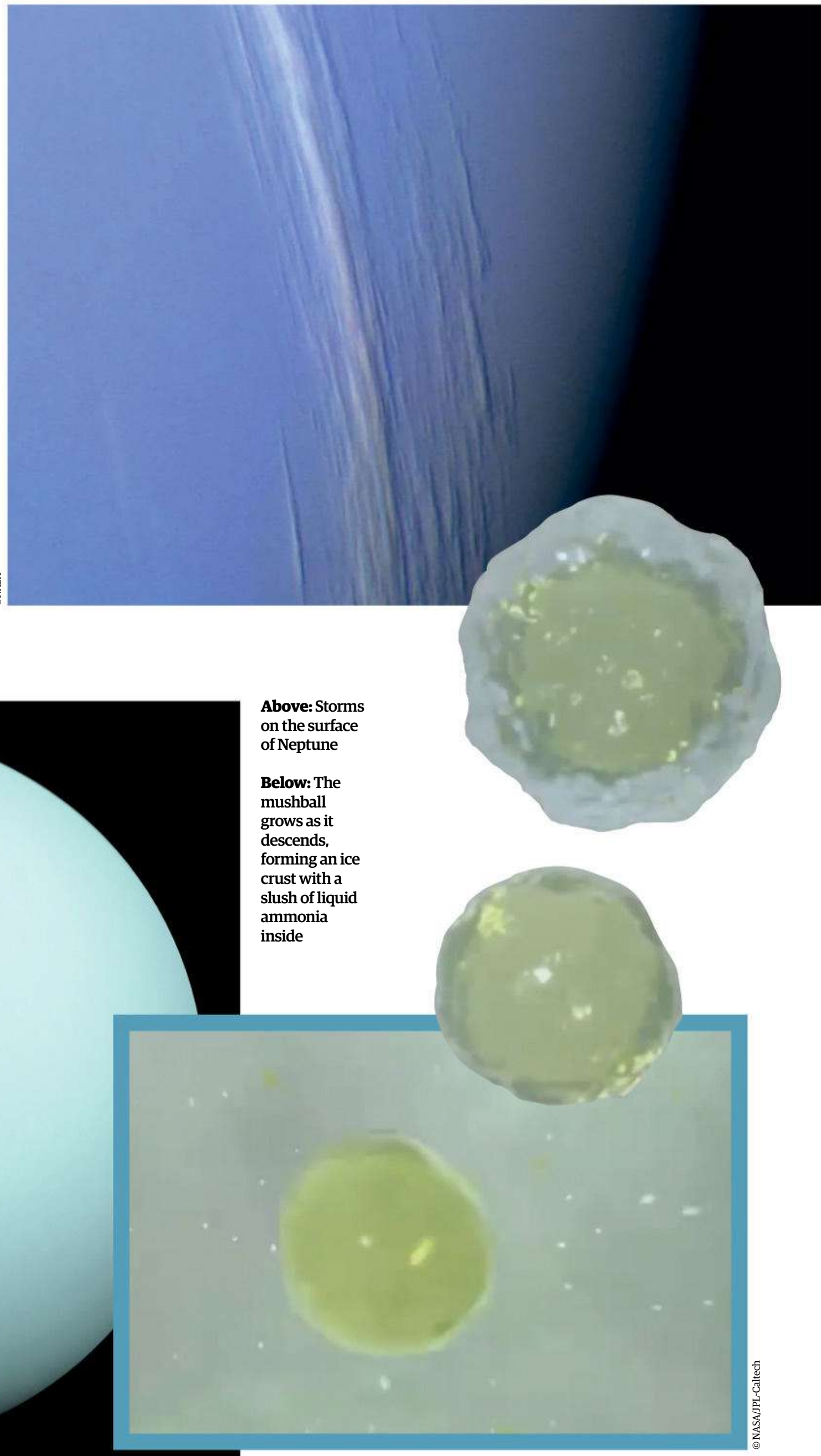
"This also confirmed the very low ammonia abundance in Uranus," says Guillot. Indeed, the detection of hydrogen sulphide high in Uranus' cloud deck was in sharp contrast with that of Jupiter and Saturn, where there is a distinct lack of this particular colourless, also foul-smelling gas above the clouds. "The most natural idea was that they were formed that way," explains Guillot, but he also questioned whether that was really the answer.

To that end, Guillot set about figuring out just why Jupiter and Saturn's upper clouds were mainly composed of ammonia ice and why those of Uranus – and presumably Neptune – were mainly hydrogen sulphide. "Last year, Imke de Pater's group at Berkeley also measured this low abundance of ammonia using observations from radio telescopes," Guillot says. This motivated him further into coming up with a theory as to why this is the case.

One thing that he was able to rule out is any suggestion that Uranus and Neptune have normal levels of ammonia above the clouds and that Jupiter and Saturn have higher than expected levels. "Jupiter's nitrogen-to-carbon ratio is



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Above: Storms on the surface of Neptune

Below: The mushball grows as it descends, forming an ice crust with a slush of liquid ammonia inside

© NASA/JPL-Caltech

HOW MUSHBALLS FORM

The theory is based on a discovery that mushballs form high in Jupiter's atmosphere

1 STRONG UPDRAFT

Here on Jupiter, a powerful thunderstorm is raging some 65 kilometres (40 miles) beneath a bank of clouds, visible during observations. Liquid water and water-ice particles are sent high into the gas giant's atmosphere by an upward current of air generated by the cloud.

2 TURNING TO ICE

The water particles are now sufficiently high enough – 19 kilometres (12 miles) up – that they all freeze and turn to ice due to the very low temperatures.

3 TRANSFORMATION

The ice particles reach an area rich in ammonia vapour, with temperatures between -85 and -150 degrees Celsius (-121 and 238 degrees Fahrenheit). The ammonia vapour is like antifreeze, liquefying the ice.

4 AMMONIA-WATER DROPLETS

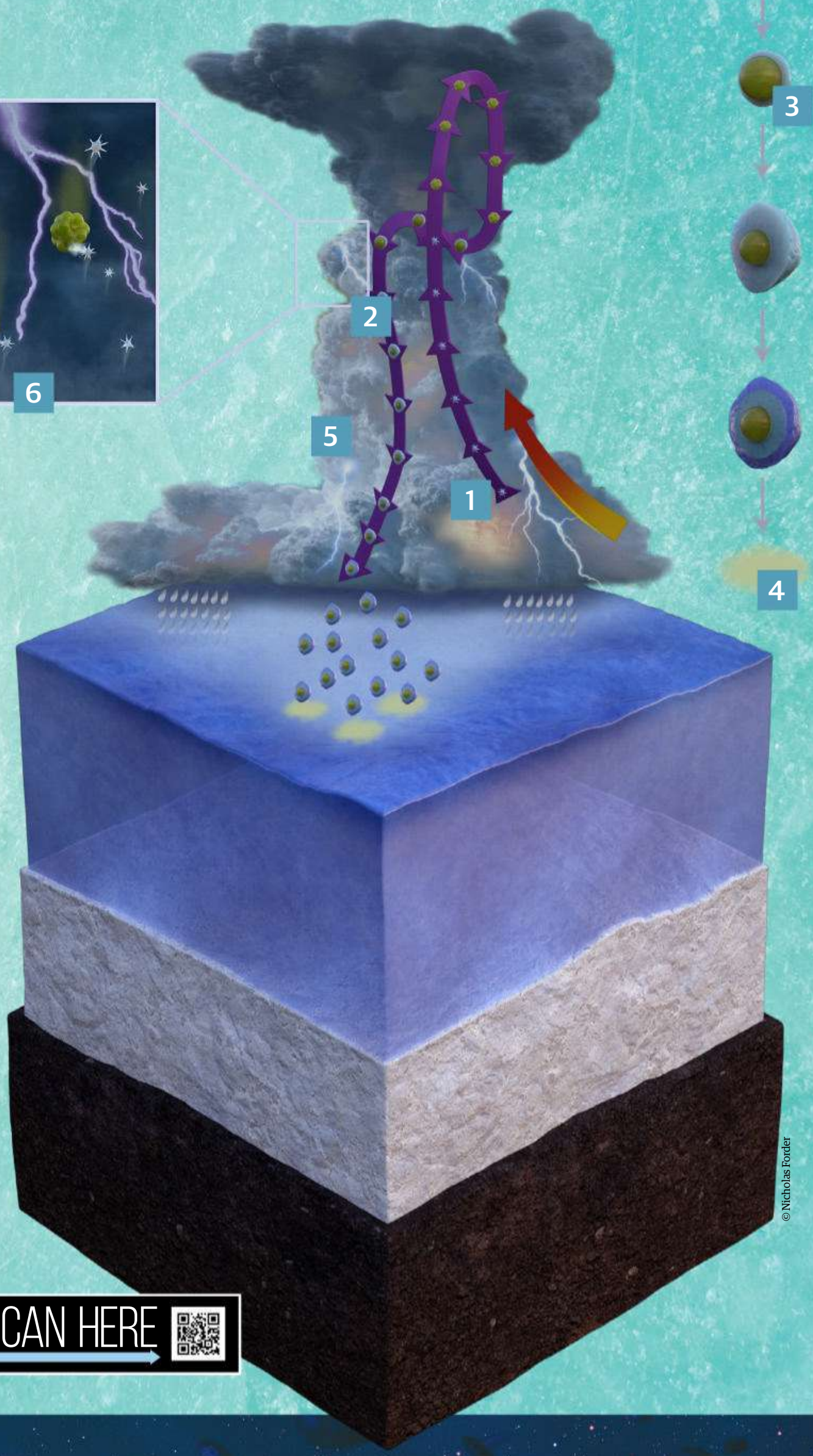
The ammonia-water droplets start to grow, becoming as heavy as one kilogram. A solid icy shell forms around a slushy ammonia-water mixture, creating what are being called mushballs.

5 FALLING DOWN

Their weight sends them plummeting down; this has the effect of moving the ammonia into the planet's deep atmosphere beneath opaque clouds. Eventually the ammonia-water core will evaporate. This transportation is why there is no detectable ammonia high in the planet's atmosphere.

6 SHALLOW LIGHTNING

Another phenomena that was observed on Jupiter is shallow lightning, which originates from clouds that contain ammonia and water. This unexpected form of electrical discharge may be caused by the mushballs.



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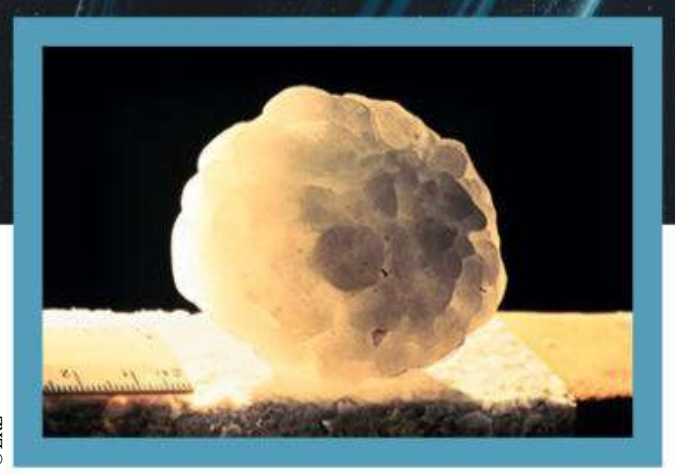

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comparable to the Sun's, so it's not unusually high," he says. "But actually we are seeing that, depending on where we look in Jupiter's atmosphere with the Juno spacecraft, the ammonia abundance may be low. We have to analyse the deepest levels of Jupiter's atmosphere to get to a 'normal' ammonia abundance."

This proved to be a crucial breakthrough. Observations from Juno suggested the gas giant's ammonia was in abundance, but that it may be hidden far deeper inside the planet than expected. Juno's science team posited that this is due to the formation of what are being referred to as 'mushballs' – liquid ammonia-water encapsulated in frozen water.

Formed by Jupiter's violent thunderstorms, mushballs are akin to slushy, ammonia-rich hailstones, believed to come into being when water-ice crystals are flung more than 25 kilometres (16 miles) above Jupiter's water clouds. The ice is then melted when the crystals come into contact with ammonia vapour, despite how freezing it is at such an altitude.

"The fact that ammonia vapour is able to melt water-ice crystals at very low temperatures provides a way to make these large 'mushballs' in the same way that supercooled liquid water is responsible for hailstones on Earth," Guillot explains. "They have been proposed to account for the unusual variations of ammonia concentration in Jupiter's atmosphere." That's because they fall and absorb ever-increasing amounts of ammonia until they reach a mass of about one kilogram. They then end up deep within the atmosphere, below the thick layer of clouds where they cannot be detected from the ground.

Scientists have also been able to detect 'shallow lightning' at Jupiter – an unexpected form of electrical discharge. "This is originating from levels where mushballs form; that is at temperatures of -70 degrees Celsius [-94 degrees Fahrenheit] or less," says Guillot. "Mushballs are the only way to account for the presence of a liquid, believed to be needed for the lightning process." On Earth, lightning originates from water clouds.

By taking the principle of mushballs and applying it to Uranus and Neptune, the assumption is that these gas giants do indeed have the expected levels of ammonia present, but that the gas has simply fallen from where it would be expected to be. Instead, it's present beneath the clouds, and that is why we can't detect such great quantities.

"That would be the implication," Guillot affirms. "We don't need Uranus and Neptune to have formed in a region of the disc devoid of ammonia. It's instead hidden – and because Uranus and Neptune are very cold, this means it's hidden

> "BECAUSE URANUS AND NEPTUNE ARE VERY COLD, THIS MEANS IT'S HIDDEN VERY DEEP"
>
> TRISTAN GUILLOT

Above: A mission to the ice giants could gain valuable data

Left: Hailstones are formed and raindrops freeze after being carried upwards by thunderstorm updrafts. Mushballs are said to be similar in makeup

THE THEORIES

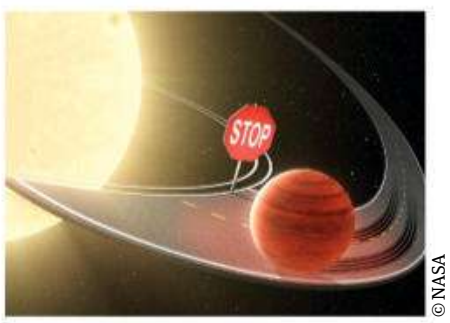
Why is there a lack of ammonia in Neptune and Uranus' atmospheres?

THE PLANETS SIMPLY FORMED THAT WAY

Neptune and Uranus may simply have formed under special conditions from material that was also poor in ammonia. That would account for an absence of ammonia in the upper atmosphere, but it would also mean that the two ice giants formed in a very different way to Jupiter and Saturn.

THE PLANETS MIGRATED FROM ELSEWHERE

Jupiter and Saturn may have formed in the coldest reaches of the protosolar disc where ammonia and nitrogen were solid; Uranus and Neptune could have formed inside the region and accumulated little nitrogen. But since Jupiter and Saturn are closer to the Sun now, the planets would have switched position.



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THERE'S AN ONGOING PROCESS INVOLVED

The alternative explanation is that something must be happening to strip the ice giants' upper atmospheres of ammonia. A downpour of mushballs made up of growing ammonia-water droplets is a strong possibility. They would take ammonia down into the deep reaches of a gas giant's atmosphere.

© NASA

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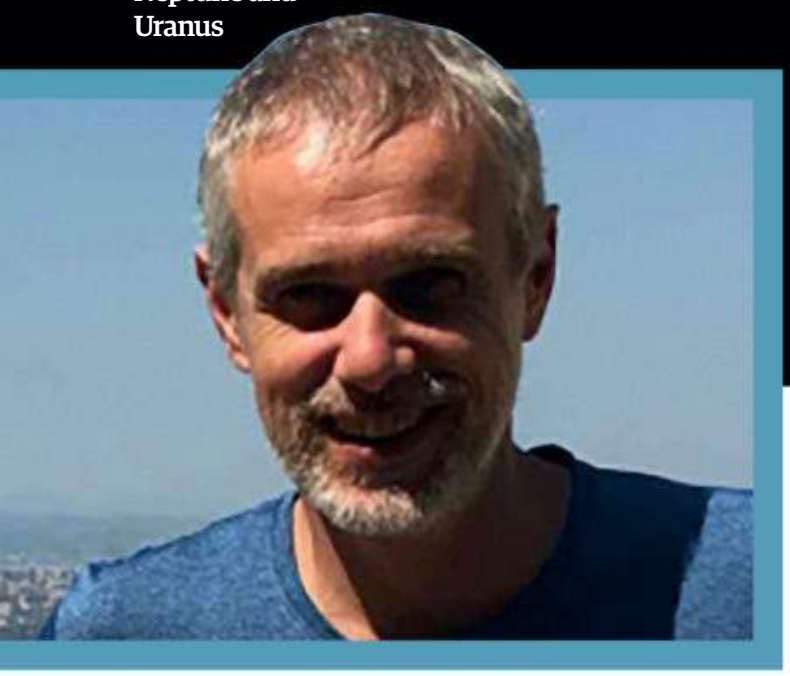
Right: Lessons learned from Jupiter could be applied to the other gas planets

Below: Researcher Tristan Guillot believes the discovery of mushballs at Jupiter can apply to Neptune and Uranus



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"THESE PLANETS ARE THE LAST ONES NEVER TO HAVE BEEN VISITED BY AN ORBITING SPACECRAFT"

TRISTAN GUILLOT

very deep, beyond the reach of present-day instruments." Guillot's theory has gone down well. He presented his work at the annual Europlanet Science Congress on 16 September, an event that was held virtually this year due to the ongoing coronavirus pandemic. During his talk, he told those watching that thermodynamic chemistry implies the process observed on Jupiter would be even more efficient on Uranus and Neptune.

In line with observations on Jupiter, he says the mushballs would again be heavier than the largest hailstones seen on Earth, but that the seed region for them would be extended, occurring at greater depths. "Because Jupiter is warmer, the base of the water cloud is around five bars – not as deep as in Uranus and Neptune, where it's deeper than 100 bars," Guillot explains.

"In Jupiter, we have been able to make these deep measurements because of the Juno spacecraft, which has been in orbit around the planet since 2016." What's needed are further investigations. Guillot is calling for "a dedicated mission to map the deep atmospheric structure and understand mixing in hydrogen atmospheres".

"The giant planets comprise 99.5 per cent of the mass of the Solar System apart from the Sun, so constraining their compositions is essential to understand how the entire Solar System came to be," he says. "It's also crucial to make sense of the many measurements of exoplanets, which cannot have the same level of detail that we can reach in our Solar System."

He also views Neptune and Uranus as a critical link between giant planets like Jupiter and Saturn and the ice giant exoplanets that are being discovered in our galaxy. "For these reasons, I strongly believe that we should send a spacecraft to Uranus or Neptune. These planets are the last ones in the Solar System never to have been visited by an orbiting spacecraft. The only close-in data we have is from the Voyager 2 flybys in 1986 and 1989. A mission to one of these fascinating planets would lead to many discoveries."

Unfortunately, such missions can feel like an age away. Although proposals have been tabled by NASA and the ESA to visit Neptune and Uranus, there are currently no firm plans for any such missions. And while China is looking to send two spacecraft to the far reaches of the Solar System in 2024, even if they get off the ground that early, they wouldn't fly past Neptune until 2038.

As you can imagine, this is incredibly frustrating, not just for Guillot, but for all planetary scientists. Many astronomers are urging space agencies to agree to a plan to visit one or both ice giant planets. Time is also ticking, given that an approaching planetary alignment would prove ideal in slashing how long it would take to travel that far out. Until then, scientists such as Guillot are going to have to continue making headway based on observations of other planets such as Jupiter. There's just a sense that there is a whole lot more to discover.

David Crookes
Science and technology journalist
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.

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BABY PLANETS MARINATE IN A LIFE-GIVING CYANIDE 'SOUP'

New data may have filled gaps in our understanding of planet formation

Reported by Adam Mann

The universe may be teeming with the molecules needed for life. The results come from the most comprehensive maps ever made of the types and locations of chemicals in the gas and dust surrounding newborn stars.

Stars spring from enormous clouds of gas and dust, which collapse under their own weight into disc-like structures. The centres of these discs heat up through friction and increased pressure until they ignite into fusion-powered stars, while the surrounding matter slowly clumps together into ever-larger chunks.

"We have known for some time that planets form in discs around young stars and that these discs contain molecules of interest for predicting the future compositions of planets," said Karin Öberg, an astrochemist at Harvard University in Cambridge, Massachusetts. A few years ago, Öberg and her colleagues decided to use the Atacama Large Millimeter/submillimeter Array (ALMA) – a telescope in Chile that sees in the radio part of the electromagnetic spectrum – as part of the Molecules with ALMA at Planet-forming Scales (MAPS) program. Because of their shapes and the bonds inside them, different chemicals vibrate in unique ways, producing telltale signatures that ALMA can capture.

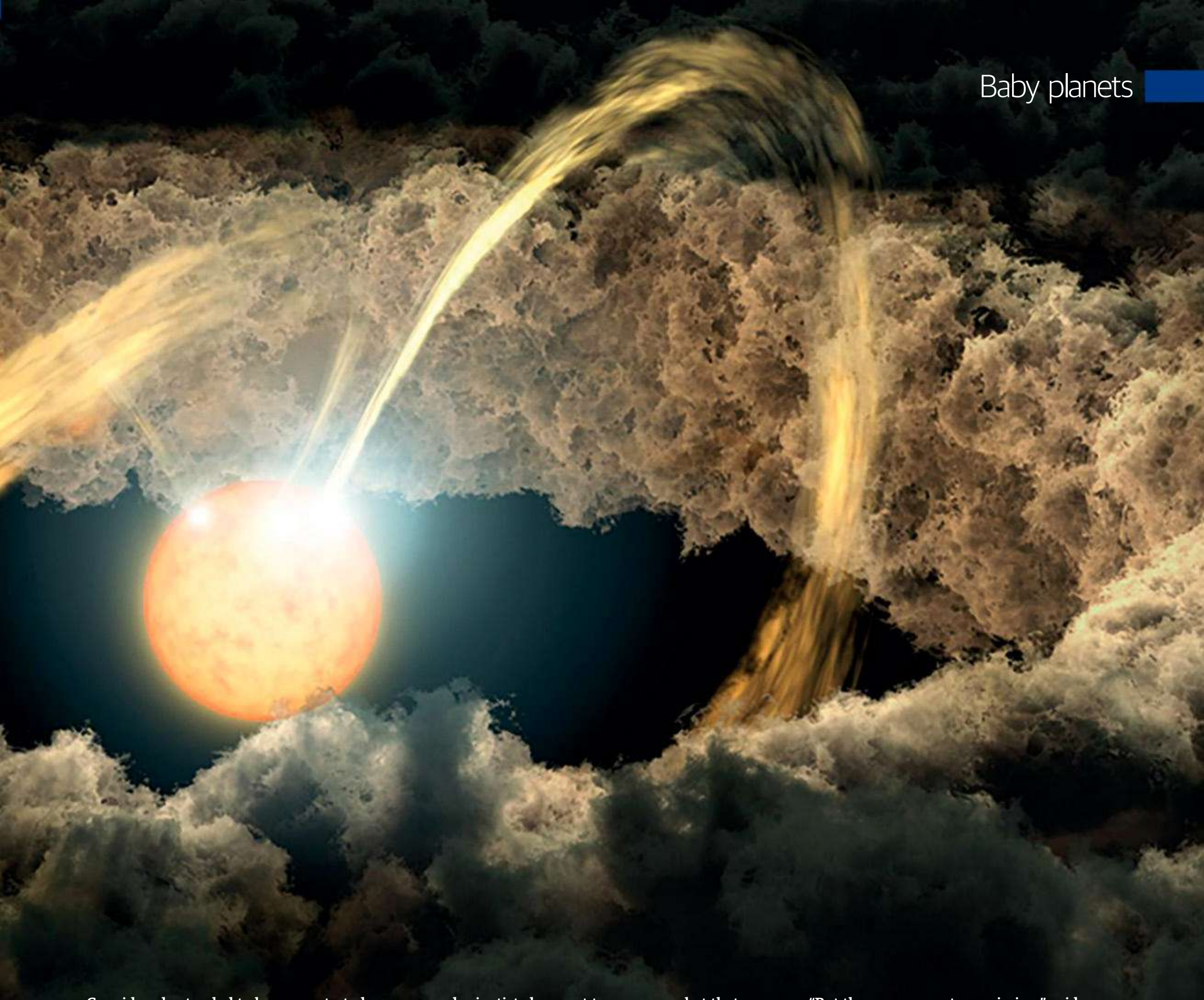
The team looked at five protoplanetary discs, all between 1 million and 10 million years old, within a few hundred light years of Earth. "That means they are in an actively planet-forming epoch," Öberg said.

MAPS determines not only the specific molecules in protoplanetary discs, but also their locations. "Planets can form at many different distances from the star," Öberg said, so it's important to know what chemicals are available in each location to build these future planets.

An astounding 20 papers from this extensive mapping project are being published in a special future issue of *The Astrophysical Journal Supplement Series*; the first of these papers was made available on the preprint server arXiv on 15 September. "What's so awesome is that there are several pieces rather than one big answer," Öberg said. "I think all 20 papers provide some different piece of the puzzle."

One of the most exciting findings for her was the abundance and distribution of a class of molecules known as cyanides. The simplest member of this family, hydrogen cyanide, is typically considered a poison, though many theories for the origin of life include a major role for this chemical class, she said.

"Seeing them in large abundance means planets are forming in the kind of soup we'd like to see" in order to fuel the emergence of life, Öberg added.



Cyanides also tended to be concentrated towards the inner parts and midplanes of the discs studied by MAPS – exactly where planets are expected to arise, she explained.

Such molecules could form only in a low-oxygen environment with lots of carbon, Öberg added. This suggests that planets will be born with carbon-rich atmospheres – another point in favour of living things, since carbon is the basis of organic chemistry.

The results show at least some of the organic building blocks of life are probably available in other stellar systems, but that doesn't necessarily make it more likely for humanity to find living organisms elsewhere. "It's promising from an origin-of-life point of view," Öberg said. "But there's still a lot of work to do."

Living creatures would have needed a certain subset of chemicals in specific amounts in order to arise spontaneously, and scientists have yet to agree on what that recipe for life was. There has been a lot of past effort into understanding the chemistry in the clouds that give rise to stars, as well as into analysing the molecules in asteroids and comets, which can contain information about later periods of planetary formation, said Kathrin Altwegg, a planetary scientist at the University of Bern in Switzerland, who was not involved in the new work.

"But there was one stage missing," said Altwegg – the stage that determined the chemistry in protoplanetary discs – and the results from this project are now helping to fill in unexplored details. The findings also imply that a great deal of complex chemical formation already takes place prior to the birth of stars and planets, suggesting that these molecules come from interstellar clouds and are widespread in space, she added.

"THE FINDINGS ALSO IMPLY THAT A GREAT DEAL OF COMPLEX CHEMICAL FORMATION ALREADY TAKES PLACE PRIOR TO THE BIRTH OF STARS"

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ASK Space

Our experts answer your questions

SOLAR SYSTEM

Why is the Sun's atmosphere hotter than its surface?

The Sun's atmosphere is hotter than its surface because of energy transported and deposited by the Sun's magnetic field. The magnetic field is created in the solar interior and carried outwards to fill the atmosphere by the motion of hot bubbles of plasma in the Sun. In the atmosphere, the field lines are constantly moved by the motions of the magnetic footpoints at the Sun's surface. These motions cause waves and reconfiguration of the atmospheric field. These in turn act to heat the atmospheric plasma.

Since the atmosphere is a plasma – a gas of electrons and protons not combined into atoms – the magnetic field and the gas are interconnected; if you move the field, you move the gas, and vice versa. There are many competing ideas as to how changes in the magnetic field lead to a heating of the plasma, and this is the focus of intense current research. New observations from both space missions and ground-based telescopes are now enabling scientists to address coronal heating, and a more clear picture should arise in the coming decade.

Dr Huw Morgan, director of research and head of Solar System physics, Aberystwyth University

Above: An image highlighting the Sun's powerful magnetic field lines

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ASTROPHYSICS

What would happen if a black hole swallowed a neutron star?

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Somewhere in the universe, a neutron star is swallowed by a black hole every ten minutes. This is the conclusion of a dying orbit, millions of years in the making, that has brought the two objects together. If the mass of the neutron star and black hole are similar, the neutron star is shredded as it spirals into the black hole, leaving behind a disc of gas that can create bright gamma, radio and other light rays. If the black hole is several times more massive than the neutron star, however, then the neutron star plunges into the black hole relatively undisturbed. What's left behind in both cases is a black hole that's heavier by about the mass of the Sun.

The orbit of the neutron star around the black hole decays because they are radiating gravitational waves – tiny ripples in the fabric of space-time. In the few milliseconds before the collision, a sizeable fraction of the mass of the Sun is converted into energy in the form of gravitational waves, and the system outputs more power (in the form of gravitational waves) than all the light from all of the stars in all of the galaxies in the entire universe combined.

Dr Rory Smith, Monash University

Did you know?

Neutron stars are some of the most dense objects in the universe, formed after massive stars die.

SOLAR SYSTEM

Why do sunrises and sunsets on Earth appear so much more vibrant during winter?

Winter sunrises and sunsets appear more vibrant during the winter thanks to a combination of lower humidity, lack of air pollution and better clouds. The beautiful pink, red and orange hues that appear at dusk and dawn are created by Rayleigh scattering – the same phenomenon that makes the sky appear blue during the day. At sunset or sunrise, the Sun's rays travel through a greater distance of atmosphere to reach our eyes, which filters out most of the shorter blue and violet wavelengths, along with some green and yellow. That leaves us with the warmer hues of the reds and oranges, leading to fiery-looking skies.

It's a myth that dust and air pollution make sunsets more dramatic. Aerosol particles attract water vapour, scattering the light and reducing the spectral purity. That means a more subdued or muted palette in summer's smog and haze. But crisp winter air tends to be drier and cleaner, especially when it comes from the Arctic, allowing purer, brighter colours to reach our eyes.

Finally, a stronger jet stream in winter creates well-defined weather systems, with clouds that form a perfect backdrop for the setting Sun.

Kirsty McCabe, broadcast meteorologist and fellow of the Royal Meteorological Society

"IT'S A MYTH THAT DUST MAKES SUNSETS MORE DRAMATIC"

KIRSTY MCCABE

© Getty

Above: The size of the black hole would affect the outcome of a collision

Right: Earth's sky alight with orange and pink tones

ASK Space

Our experts answer your questions

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SPACE EXPLORATION

What was it like to go on a spacewalk? What does it actually feel like?

When you first get into space, you're inside the cabin inside the spacecraft. You get to do your job, but you're wearing regular clothes. You are floating, which is really cool, and when you look through the window it's magnificent. It's kind of like looking through the glass of an aquarium. When you go on a spacewalk, you're kind of like a scuba diver, interacting with the environment. You truly feel like a spaceman.

It wasn't like when I was in the spaceship with other people; I was the only guy in the spacesuit. I was out there in space by myself, with my own life-support system, and I could look anywhere I wanted. I could look and see the planet from where Hubble is. I thought this would be the view from heaven. But then, I thought, it was more beautiful than that. It was like looking into a paradise. The brightness of the Sun when you leave the atmosphere... Wow! There it is! It looks just like a star. And it's bright, really bright. It's the brightest bright I've ever experienced. Getting to see the planet and the stars on a spacewalk was truly an incredible experience.

Mike Massimino, engineer and former NASA astronaut

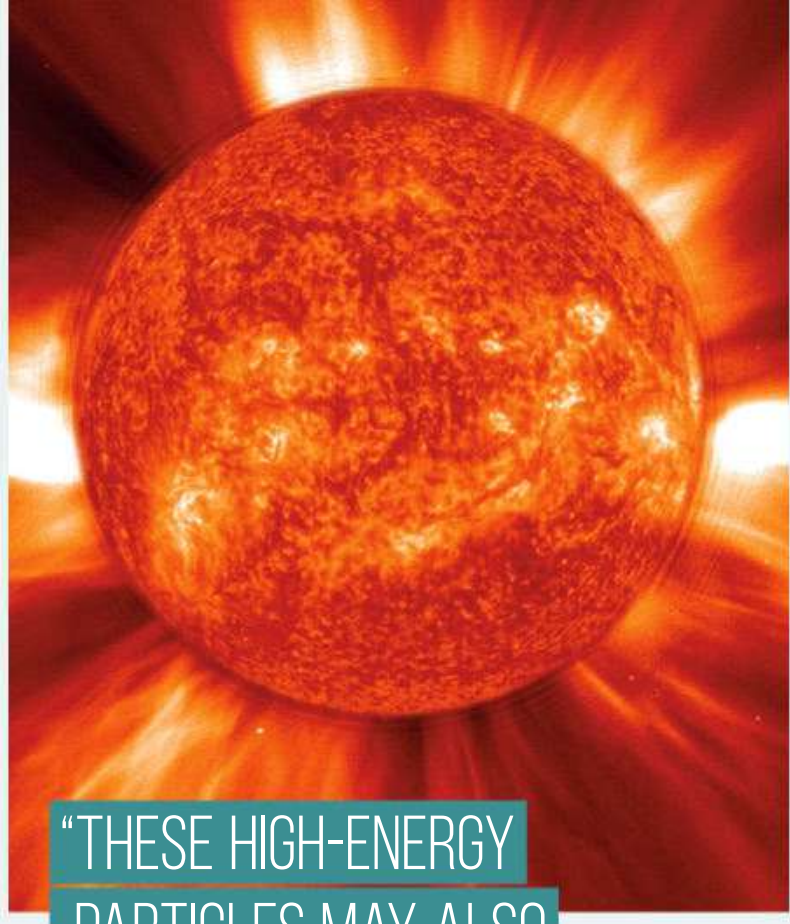
SOLAR SYSTEM

Is space weather a threat to satellites?

Space weather is a significant threat to satellites in orbit. The biggest threat to any human-made objects in space are the solar storms that may substantially increase the flow of charged particles from the Sun. Solar flares emerging from sunspot groups and regions of magnetic anomalies on the solar disc may be associated with phenomena called solar particle events, in which electrons and protons from the Sun are accelerated to relativistic speeds. When these particles hit a satellite, its solar panels and onboard electronics may experience radiation damage that would normally take several years in space to accumulate. These high-energy particles may also cause malfunctions in satellite electronics and memory circuits, causing transient or permanent damage and potentially even causing the loss of the satellite.

Big solar flares are also often associated with coronal mass ejections – huge eruptions with billions of tonnes of matter from the Sun ejected into space at speeds reaching up to 3,000 kilometres (1,864 miles) per second. When such a cloud of plasma hits the magnetic field around Earth, it may trigger a geomagnetic storm that makes the radiation environment for satellites much harsher than it is normally.

Particularly in geostationary orbit, where most of our communications satellites are, parts of the satellites may become electrostatically charged, and the onboard electronics can be damaged by the eventual discharge. Geomagnetic storms may also produce very high-energy electrons in the outer radiation belt – 'killer electrons' that can permanently damage satellite electronics and kill the mission.



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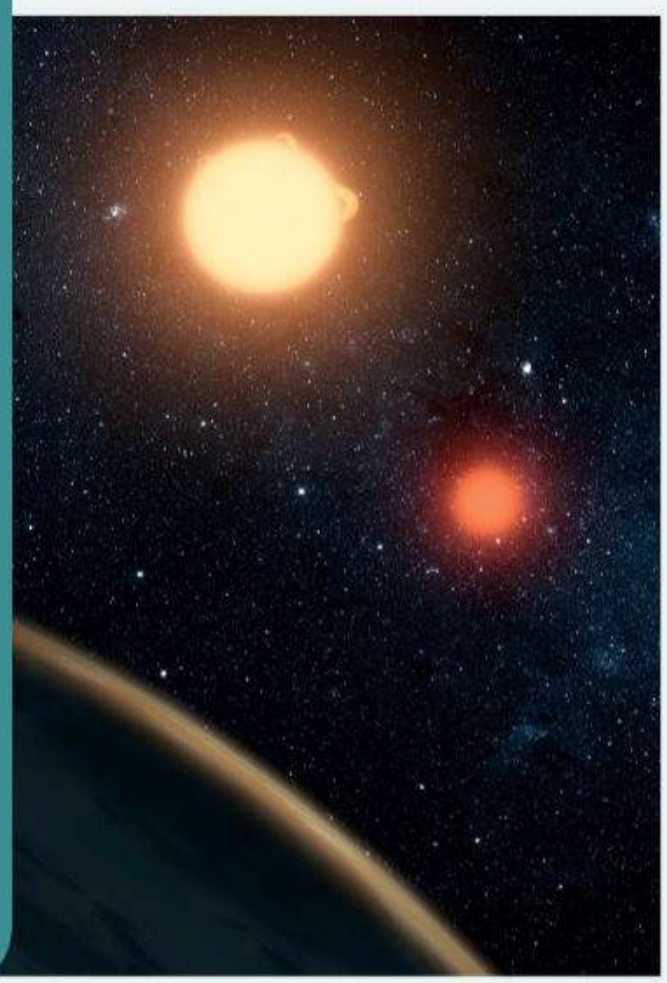
"THESE HIGH-ENERGY PARTICLES MAY ALSO CAUSE MALFUNCTIONS IN SATELLITE ELECTRONICS"

MELANIE HEIL & JUHA-PEKKA LUNTAMA

Melanie Heil, space weather space segment coordinator in the European Space Agency Space Weather Office, and Juha-Pekka Luntama, head of the Space Weather Office



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PLANETS

Can a planet orbit more than one star?

A planet can certainly orbit more than one star, just like the planet Tatooine in *Star Wars*. Thanks to Kepler and the Transiting Exoplanet Survey Satellite (TESS), we have discovered around a dozen circumbinary planets – those orbiting around binary stars – which we sometimes call Tatooines. The orbits of these planets encircle the central binary far enough away for the whole system to be dynamically stable. We also know of planets which orbit within stellar binaries; such planets orbit around one of the stars, with the other star moving on a wider orbit. And two stars is not a limit. For example, our closest stellar neighbour, Proxima Centauri, is part of a loosely bound triple system and is known to be host to at least one planet. Also, very recently it was proposed – albeit based on indirect evidence – that a young stellar triple system, GW Orionis, may be orbited by a massive planet in a circumtriple configuration. Planets are not averse to residing in crowded stellar systems.

Professor Roman Rafikov, Department of Applied Mathematics and Theoretical Physics, University of Cambridge

SOLAR SYSTEM

Where do meteorites that fall on Earth originate from?

Meteorites originate from celestial bodies in our Solar System. While most meteorites come from asteroids, they have also been identified from the Moon and Mars. We know where meteorites originate from by studying their compositions, which are very diagnostic. Violent collisions between bodies in our Solar System knock fragments off the surfaces of large bodies, like the Moon and Mars, and completely disrupt smaller bodies like asteroids, sending rock fragments into Earth-crossing orbits.

Fortunately for scientists, since meteorites come from many different celestial bodies, they represent many different stages of planetary evolution. Studying them allows us to understand what our Solar System formed from and how it evolved. For example, chondritic stony meteorites formed shortly after the birth of the Solar System four-and-a-half billion years ago, providing a snapshot of the nature of the building blocks of Earth. In contrast, lunar and Martian meteorites are younger and provide a way to study the later stages of planetary evolution, helping us understand how important components, such as water, are stored in minerals in large, evolved planetary bodies.

Dr Jemma Davidson, Center for Meteorite Studies, Arizona State University

Below: Meteor showers are caused when Earth passes through a comet or asteroid's dust cloud

Did you know?

Earth is constantly pelted by space dust and debris, but most of it burns up as it enters the atmosphere.

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From the top astronomy publisher comes the bestselling stargazing handbook to the planets, stars and constellations visible from the Northern Hemisphere. There are six pages for each month, covering January to December 2022. This practical guidebook is an easy introduction to astronomy and a useful reference for seasoned stargazers.

Designed for Britain and Ireland but usable anywhere in the world between 40 and 60 degrees north, it covers most of Europe, southern Canada and the northern United States. Inside you'll find advice on where to start looking and a map of dark-sky sites to avoid light pollution, charts for the circumpolar and seasonal constellations, easy-to-use star charts for each month with descriptions of objects and events to look for in 2022, positions of the Moon, visible planets and eclipses.

"NEVER MISS A NIGHT SKY EVENT, WHEREVER YOU ARE IN THE WORLD"

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Discover all you need to know about eclipses, blue moons, supermoons, conjunctions and occultations, while a comprehensive section covers astrophotography using lenses, telescopes and smartphones, including video and how to process your images. Also included is a photographic atlas of lunar features with plates and annotated maps. A glossary of key terms, index of lunar features and software references are also provided. There's also an eBook version available for £6.49, optimised for colour tablets.

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Follow the progress of constellations throughout the seasons with this beautiful companion to the night sky. With the aid of easy-to-understand monthly calendars and maps, you will chart the rhythm of the lunar phases, discover events that light up the sky for brief periods and explore the rich tapestry of characters that adorn the starry canvas overhead.

Never miss a night sky event, wherever you are in the world, with this month-by-month guide: go meteor spotting, track the phases of the Moon and explore the constellations with worldwide coverage – with details inside for both the Northern and Southern Hemisphere – and discover fascinating celestial facts and notable astronomical anniversaries.

The *Night Sky Almanac 2022* is written and illustrated by astronomical experts Storm Dunlop and Wil Tirion and approved by the astronomers of the Royal Observatory Greenwich.

PLANISPHERE: LATITUDE 50°N £12.99

A star finder that allows visible stars to be identified for any date and time for certain locations in the Northern Hemisphere, it's compiled by astronomical experts Storm Dunlop and Wil Tirion and approved by the astronomers of the Royal Observatory Greenwich.

It's an easy-to-use practical tool to help astronomers identify the constellations and stars every day of the year. Just dial in the date and time by rotating the inner plastic disc showing the time until it lines up with the relevant day of the year on the outer ring. The part of the sky appearing on the planisphere will then show the arrangement of the stars above you.

This star chart is suitable for use anywhere in Britain and Ireland, Northern Europe, Canada and the northern United States. It's best viewed as near to latitude 50 degrees north as possible. The moveable disc also comes in a wallet which contains further information about stargazing.

ASTROPHOTOGRAPHY FOR BEGINNERS

IN THIS GUIDE, WE COVER EVERYTHING FROM CAMERA SETTINGS TO EQUIPMENT TO EDITING TIPS

Written by Stuart Cornell

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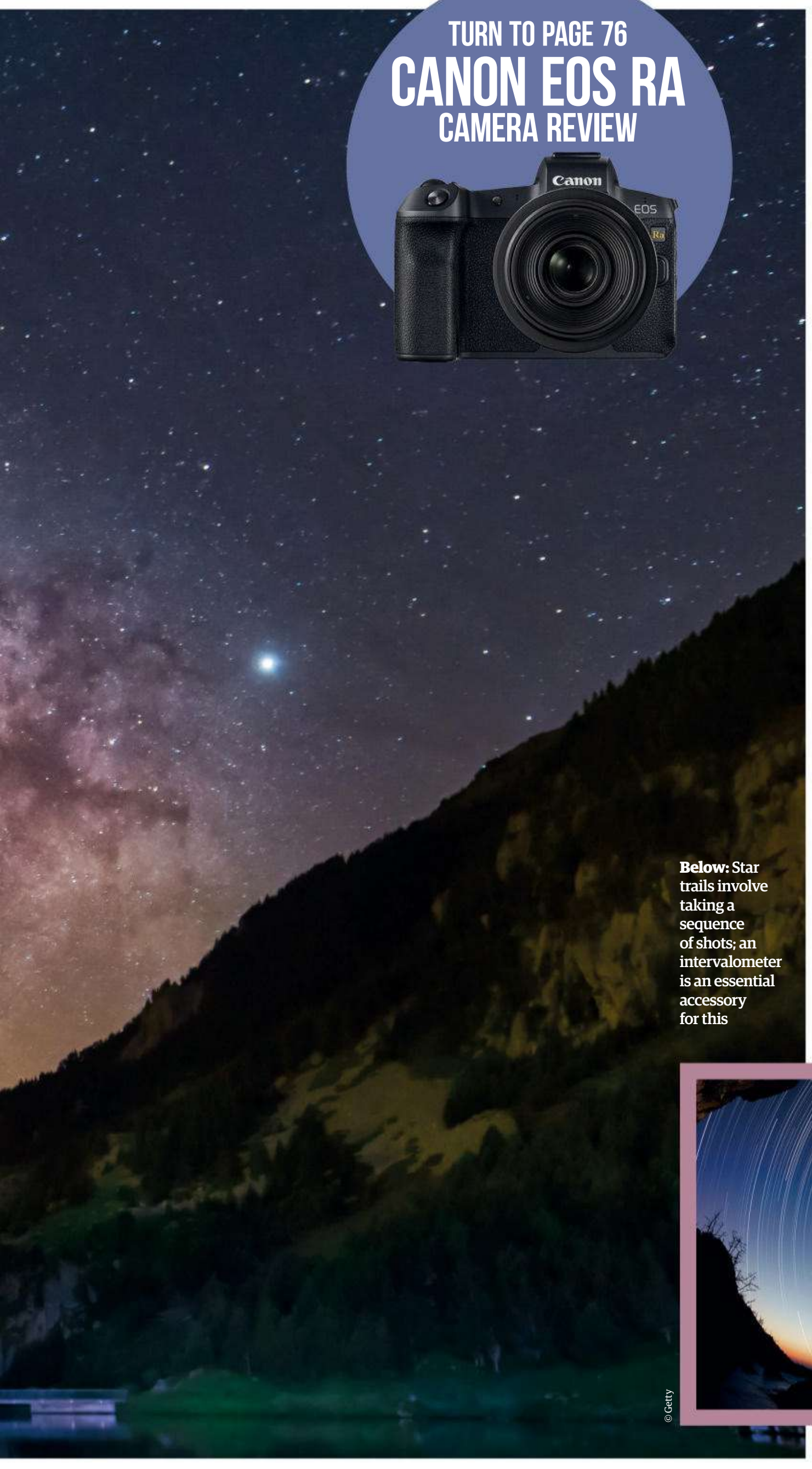
TURN TO PAGE 76

CANON EOS RA CAMERA REVIEW



Below: Star trails involve taking a sequence of shots; an intervalometer is an essential accessory for this

© Getty

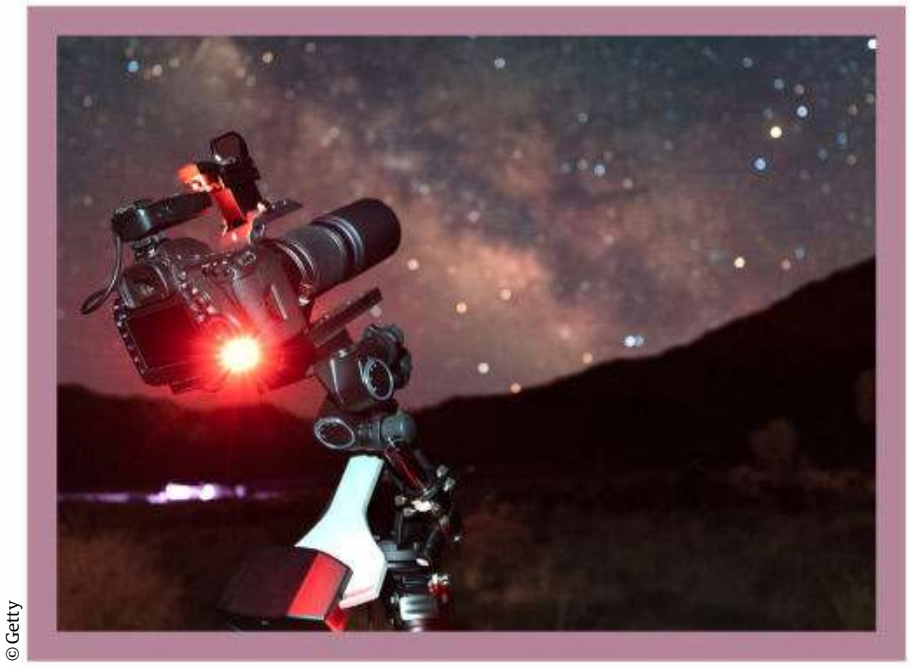
It's tough to know where to start with night-sky photography. Our astrophotography for beginners guide is here to make things a little easier for you and to demystify the process of shooting the stars. While astrophotography as a hobby can require both financial investment and plenty of patience, the results are often spectacular. You can achieve great star photos with any camera – and even some smartphones – though one of the best cameras for astrophotography will help. Once you know the basic techniques, there are so many ways to get creative with your astroimages.

While it can be time-consuming, the best advice we can give astrophotography beginners is to just do some research, have a go and learn from your mistakes each time. Pretty soon you'll have some spectacular night-sky images to show your friends. Ideally you'll be using a DSLR or mirrorless camera in Manual mode. We always recommend manual focusing when shooting astro, as most sensors – even in low-light autofocus – simply won't be able to focus on the night sky. Full-frame cameras will perform the best in low-light situations as they have a larger sensor and will therefore capture more light. However, modern crop-sensor cameras are very capable for astrophotography and are a more affordable option than full-frame cameras.

As a rough guide, full-frame cameras can cost upwards of £700 ($940); it will likely set you back £1,500 to £2,000 ($2,000 to $2,700) for a good

"DO SOME RESEARCH, HAVE A GO AND LEARN FROM YOUR MISTAKES EACH TIME"

Astrophotography for beginners



© Getty

mirrorless or DSLR with the ability to take sharp images at higher ISO settings.

Crop-sensor or APS-C cameras are usually £300 ($400) and up and are more than capable. A wide or super-wide angle 'fast' lens in the 12 to 35mm range is best suited to landscape photography and astrophotography. Wide-angle focal lengths allow you to capture a good portion of the night sky, as well as some of the landscape for foreground interest. A 'fast' lens is one that has a large maximum aperture – in other words, a small f-stop number. A lens with a maximum aperture of f/2.8 or lower is considered to be a fast lens and is excellent for astrophotography.

A lens like the Rokinon (Samyang) 14mm f/2.8 is a great lens to get started with and is very affordable. If you're ready to spend a little more, the Sigma f/1.4 14mm Art lens is superb. If you don't have a fast lens just yet, you can still use the kit lens that came with your camera. Just make sure you operate at the maximum available aperture size – typically around f/4 on stock kit lenses.

Astrophotography involves taking long exposures, so a sturdy tripod is one of the most important pieces of equipment. If your camera moves at any point during a long exposure, your image won't be sharp and may come out blurry. Camera movement from the wind will quickly ruin an image, so a solid base for your camera is a must. Something like the Manfrotto BeFree is a good place to start, as it's relatively light and sturdy.

Keep your hands free to operate your camera by using a headlamp at night, and if possible use red-light mode (if it has one) to preserve your night vision. A headlamp is also helpful for 'light painting' objects in the foreground of your images. A remote shutter release is also recommended, as this will allow you to trigger your shutter while minimising the risk of introducing vibrations. If you don't have a remote shutter release, use the timer delay on your camera to ensure there is no movement of the camera during an exposure.

Above: Stargazing apps can let you know the best time to shoot

Right: Shooting the night sky near a lake is a great opportunity to capture stars reflected in the water

Below: The Moon can make an interesting subject, especially during a lunar eclipse

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BEST PHOTO-EDITING APP FOR BEGINNER ASTROPHOTOGRAPHERS

CyberLink PhotoDirector 13

This software is easy to use and packs in lots of social media-friendly features, but it might not suit experienced astrophotographers.

OPTIMAL SETTINGS

There are a handful of basic rules you can follow to maximise your chances of nailing that astroshot

CAMERA SHOOTING MODE

M Shoot in manual. You will need to set the shutter speed and ISO manually. And don't forget that you want your aperture as wide as possible in almost all situations, so set it to an f-number of f/4 or lower. We recommend f/2.8 or lower.

IMAGE FILE TYPE

RAW Astrophotography can be broadly split into two separate areas: photography and post-processing. In order to process your newly acquired astroimages back at home, you'll need to shoot in RAW so that you capture and retain as much data as possible.

SHUTTER SPEED

The aim is to capture as much light as possible while at the same time avoiding noticeable star movement in the image, known as star trailing. The longer the focal length of your lens, the shorter the shutter speed will need to be in order to avoid star trails.

How do you calculate the correct shutter speed? We use the '500 rule'. In its simplest form, this is 500 divided by the focal length of the lens. If you're using a 20mm lens, this would be 500/20, so 25 seconds. This only applies to full-frame cameras. For a crop-sensor camera, the crop factor needs to be taken into account, so in this instance we would recommend using a base value of 300 for your calculations. We recommend starting with an exposure of 20 seconds, which is about the longest you can leave the shutter open before stars begin to trail. See how that looks, then adjust.

APERTURE

Open your aperture to at least f/2.8 if your lens allows, or the lowest f-stop possible. You want to capture as much light as possible during your exposure.

ISO

ISO The higher the ISO, the more the light signal is amplified from your camera sensor. You will need to shoot at a high ISO, but there's a trade-off. The higher the ISO, the more noise you will see in the image. ISO 3200 is a good starting point. You may need to adjust down to something like ISO 1600 if there's a lot of ambient light or light pollution. Very dark skies may require you to boost the ISO to 6400, but we wouldn't recommend going higher than this.

FOCUSING IN THE DARK

First, set your camera to manual focus – autofocus won't work in the dark. Then use the 'Live View' feature of your camera to display an image preview on the camera's LCD screen. Identify a bright star or distant light source like a streetlight on the LCD display and digitally zoom in to that point of light. Once you have done this, adjust the focus ring until the star or light source becomes as small as possible. Your focus is now set!

Now all you have to do is compose the frame, take the shot and wait for the image to pop up on the LCD display. If your foreground is looking dark, try 'light painting' your subject with a headlamp or your smartphone light during the exposure to help brighten the scene. You may need to adjust the ISO or aperture slightly to find what works best for your location, but you are now firmly on your way to capturing your own images of the beautiful night sky.

TOP TIPS AND ADVICE

Tricks to make your astrophotography images really stand out

FOREGROUND

If you're trying to balance light between the foreground and the night sky, we suggest you take multiple exposures and merge the images when you edit, as you will require different settings to get the best of each. You may even find that getting your foreground shots an hour or so earlier, during the blue hour, will help, as there is more light to work with for your foreground objects. This isn't always possible, though.

REFLECTIONS

If you're shooting the night sky near a lake and the weather is still, there's a great opportunity to reflect the stars in the water. There are several ways to do this, depending on the conditions. We prefer to do the hard work in the shoot, so would suggest changing your focal point to the water and taking an exposure, then setting your focus back to the night sky and taking the exact same shot. You can merge them later. You may find you need to balance your shutter speed a little here, depending on the conditions – a 20-second exposure will capture the reflection of the stars, but you may pick up movement on the water that reduces the clarity. You could try shorter exposures for your reflection shot, but may have to work harder to bring out the stars when editing. Something like Lightroom's linear gradient edits are perfect for bringing out the clarity and sharpness of reflections.

WHITE BALANCE

While we'd usually recommend setting your white balance to a slightly cooler temperature for astroshots, you can experiment with either the manual white balance settings or the presets to create interesting tints and variations to your shots. If you're getting a little light pollution, adjusting the white balance can actually make it look like a feature of the photo. We recommend cooling it right down and seeing the effect that has, although you'd need a gradient filter to reduce noise if you're closer to an urban area.

GRADIENT FILTERS

If you've got plenty of cash and want to try shooting near a little light pollution so you can get urban foreground images, you could consider using a graduated neutral density filter, like the 0.3, 0.6 and 0.9 landscape filters from Lee. What these allow you to do is block out some of the light at the bottom of your image. If you're getting noise pollution from the ground upwards, applying a 0.6 filter allows you to essentially make the bottom of your image about two stops darker. It all depends on your location, and we'd always recommend shooting in dark skies for astrophotography, but it is possible to photograph stars near urban areas with the right kit and a little bit of experimentation.

"YOU'LL NEED TO BE IN A DARK-SKY AREA TO BE ABLE TO CAPTURE DETAILED IMAGES"

Above: For the best results, find a dark-sky location with minimal or no light pollution

If you're shooting star trails and need to take sequences of shots, then an intervalometer is an essential accessory. However, this is quite an advanced form of astrophotography, so we wouldn't necessarily suggest you head out to get one right away. Try to take clear pictures of stars, nebulae, star clusters and nearby galaxies before you advance to new techniques.

When planning your astrophotography shoot, there are a few things to take into consideration. It may sound obvious, but you'll need to be in a dark-sky area to be able to capture detailed images of the night sky. Head away from urban areas and find a dark-sky location with minimal or no light pollution. There are many useful websites, like **darksitefinder.com** and **lightpollutionmap.info**, which will help you to find a suitable location to shoot. However, if you're planning on taking a lot of astrophotos and you want to get weather reports and guidance on where to point your camera when you shoot, the best stargazing apps are low in cost, and they're so helpful when it comes to selecting your location and letting you know when the best time to shoot is.

The night sky is constantly changing throughout the year, and knowing what you are going to photograph is a key component of astrophotography. There are excellent apps like Stellarium and Star Walk 2 which allow you to visualise how the night sky will look at any time and date for a specific location.

Stuart Cornell
Astrophotographer
Stuart is a landscape and night-sky photographer based in Cornwall, UK. He has had his work featured in several national publications.

© Getty

TOP TARGETS FOR BEGINNERS

ANDROMEDA (MESSIER 31)

Constellation: Andromeda

Located 2.5 million light years away is the nearest large spiral galaxy to the Milky Way. Andromeda can be spotted by first finding the constellation of Cassiopeia. Locate its star Schedar, which will appear to point to the Andromeda Galaxy.

THE PLEIADES (MESSIER 45)

Constellation: Taurus

Also known as the 'Seven Sisters', this open star cluster consists of more than 800 stars. To find the Pleiades, follow the three stars in Orion's Belt and then go up past his bow. The first bright star is Aldebaran, and the cluster is located a little further along.

THE ORION NEBULA (MESSIER 42)

Constellation: Orion

This emission-reflection nebula is one of the brightest nebulae in the sky and can even be visible to the naked eye. You can find the nebula halfway down Orion's Sword, appearing as a hazy-looking star.

x3 Iamges © Getty

WHAT'S IN THE SKY?

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"A PLANET IS IN CONJUNCTION WITH THE SUN WHEN IT AND EARTH ARE ALIGNED ON OPPOSITE SIDES OF THE SUN"

RED-LIGHT FRIENDLY
In order to preserve your night vision, you should read our observing guide under red light

4 DEC TAKE CARE!
Total or partial solar eclipse visible from Australia, South Africa and South America

7 DEC
Conjunction between the Moon and Venus in Sagittarius

7 DEC
The Moon and Venus make a close approach, within 1°51' of each other in Sagittarius

8 DEC
Conjunction between the Moon and Saturn in Capricornus

8 DEC
The Moon and Saturn make a close approach, within 4°04' of each other in Capricornus

9 DEC
Conjunction between the Moon and Jupiter in Capricornus

14 DEC
The Geminid meteor shower reaches its peak

Source: Wiki Commons© David St. Louis

15 DEC
Open star cluster NGC 1981 in Orion's Sword is well placed for observation

21 DEC
December solstice

22 DEC
The Ursid meteor shower reaches its peak

JARGON BUSTER

Conjunction
A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)
Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

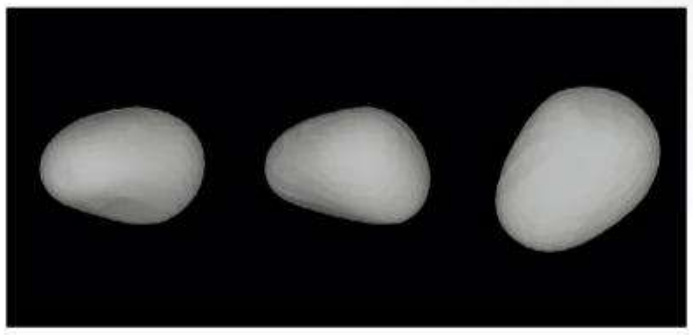
Declination (Dec)
This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Magnitude
An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Opposition
When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Greatest elongation
When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

7 DEC
Venus is at its greatest brightness in the evening sky, shining at -4.7 in Sagittarius


Source: Wiki commons © Astronomical Institute of the Charles University

9 DEC
The Moon and Jupiter make a close approach, within 4°13' of each other in Capricornus

10 DEC
Asteroid 44 Nysa reaches opposition, glowing at magnitude +9.1 in Taurus

13 DEC
Venus is at its highest altitude in the evening sky, shining brightly at magnitude -4.4

16 DEC
The Comae Berenicid meteor shower reaches its peak

Source: Wiki commons © Stephen Rahn

19 DEC
The Leonis Minorid meteor shower reaches its peak

28 DEC
Open star cluster NGC 2232 in Monoceros is well placed for observation

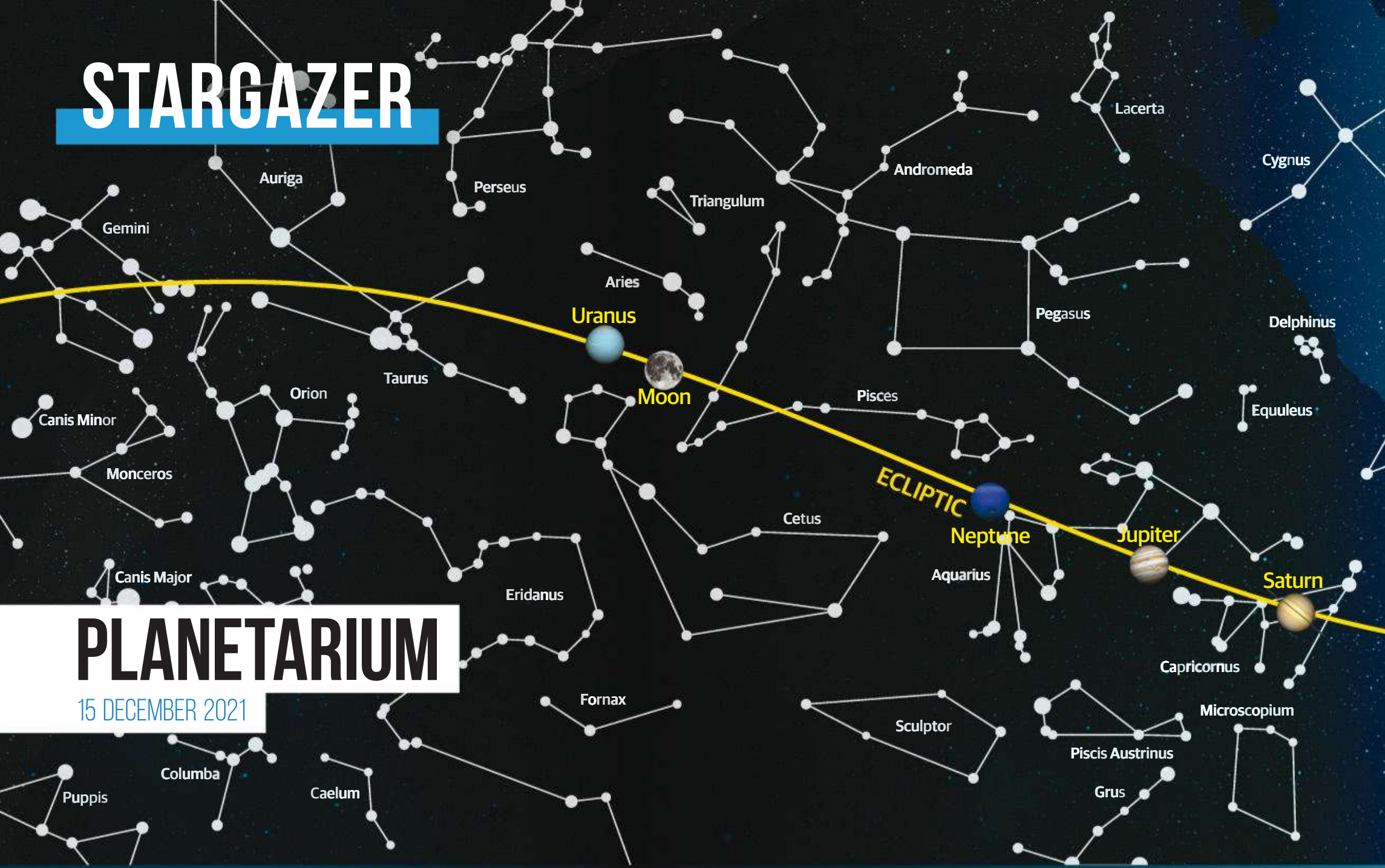
29 DEC
Open star cluster NGC 2244 in Monoceros is well placed for observation

- Naked eye
- Binoculars
- Small telescope
- Medium telescope
- Large telescope

STARGAZER

PLANETARIUM

15 DECEMBER 2021



OPPOSITION

EVENING SKY

MOON CALENDAR

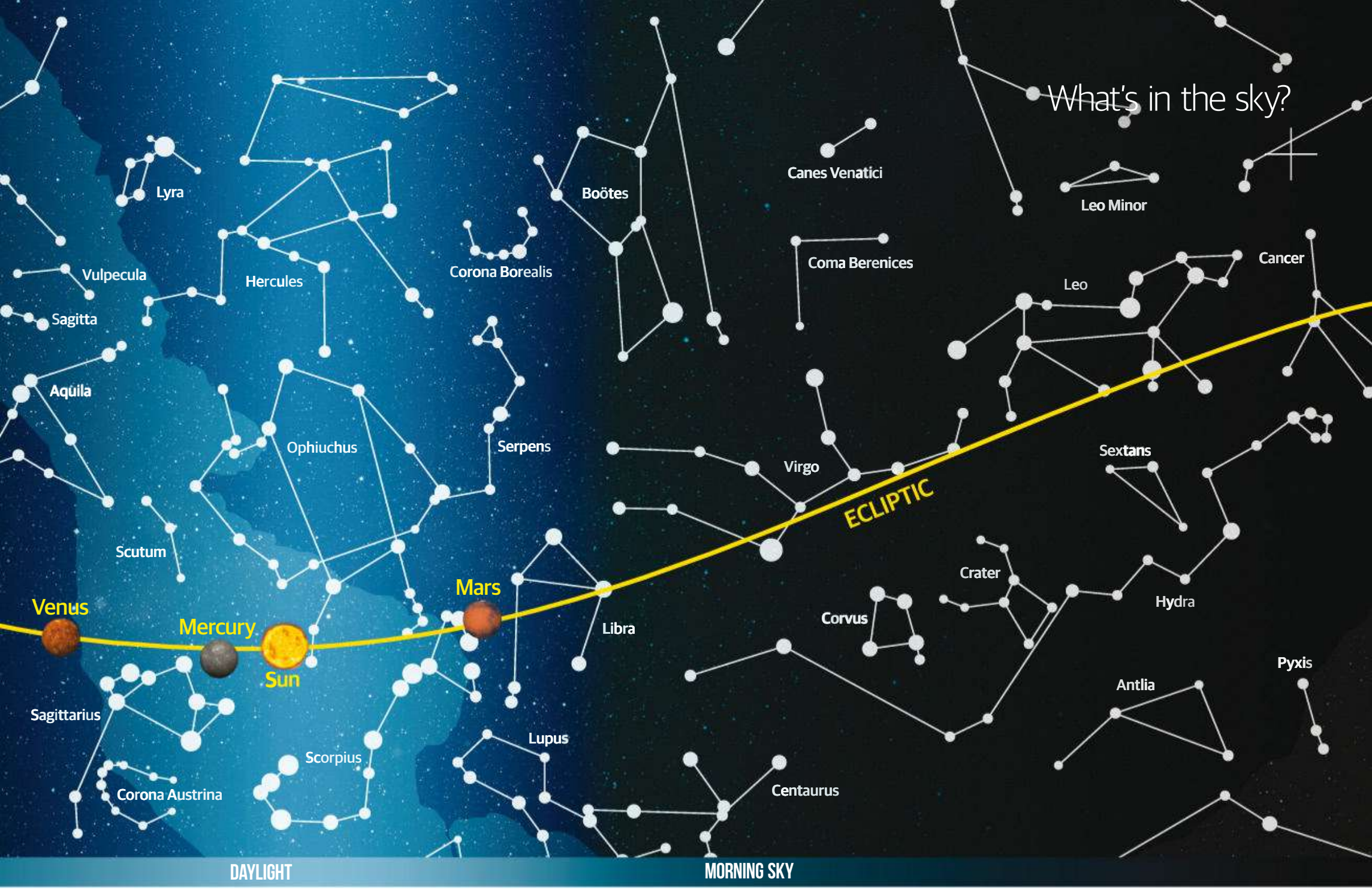
* The Moon does not pass the meridian on 19 December

2 DEC 5.4% 04:59 14:49	3 DEC 1.1% 06:31 15:15	4 DEC NM 0.1% 08:03 15:51	5 DEC 2.3% 09:28 16:42			
6 DEC 7.8% 10:38 17:49	7 DEC 15.7% 11:28 19:10	8 DEC 25.3% 12:03 20:34	9 DEC 35.9% 12:28 21:57	10 DEC 46.8% 12:46 23:15	11 DEC FQ 57.4% 13:01 --:--	12 DEC 67.4% 00:30 13:15
13 DEC 76.4% 01:42 13:28	14 DEC 84.3% 02:53 13:41	15 DEC 90.7% 04:03 13:56	16 DEC 95.5% 05:14 14:15	17 DEC 98.7% 06:24 14:38	18 DEC 99.9% 07:32 15:08	19 DEC FM --:--%* 08:35 15:48
20 DEC 99.3% 09:29 16:39	21 DEC 96.8% 10:12 17:40	22 DEC 92.4% 10:46 18:49	23 DEC 86.3% 11:11 20:01	24 DEC 78.6% 11:32 21:16	25 DEC 69.5% 11:49 22:31	26 DEC 59.3% 12:04 23:48
27 DEC TQ 48.4% 12:18 --:--	28 DEC 37.2% 01:07 12:33	29 DEC 26.3% 02:29 12:50	30 DEC 16.4% 03:56 13:12			

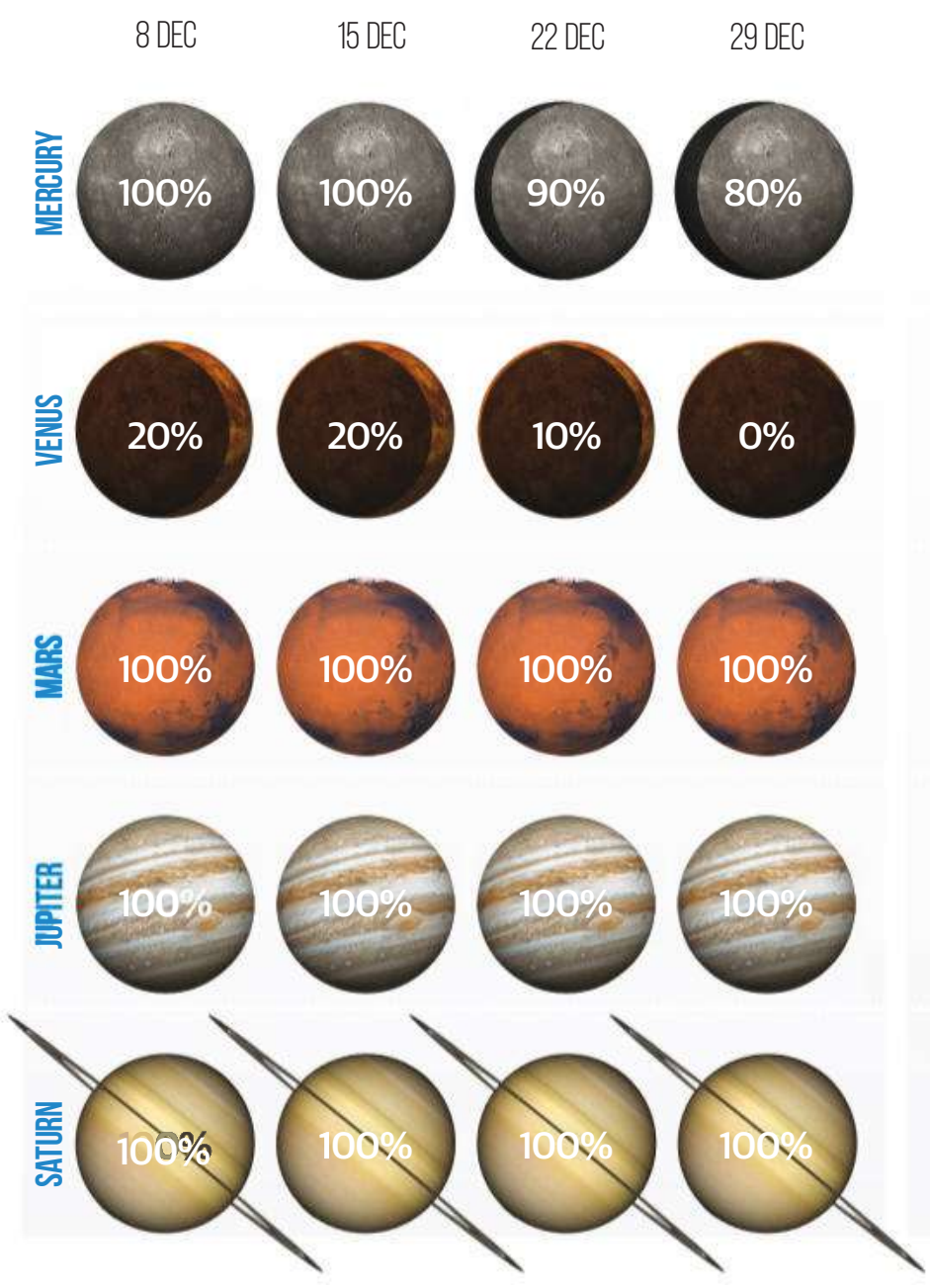
% Illumination
Moonrise time
Moonset time

FM Full Moon
NM New Moon
FQ First quarter
TQ Third quarter

All figures are given for 00h at midnight (local times for London, UK)



ILLUMINATION PERCENTAGE



PLANET POSITIONS

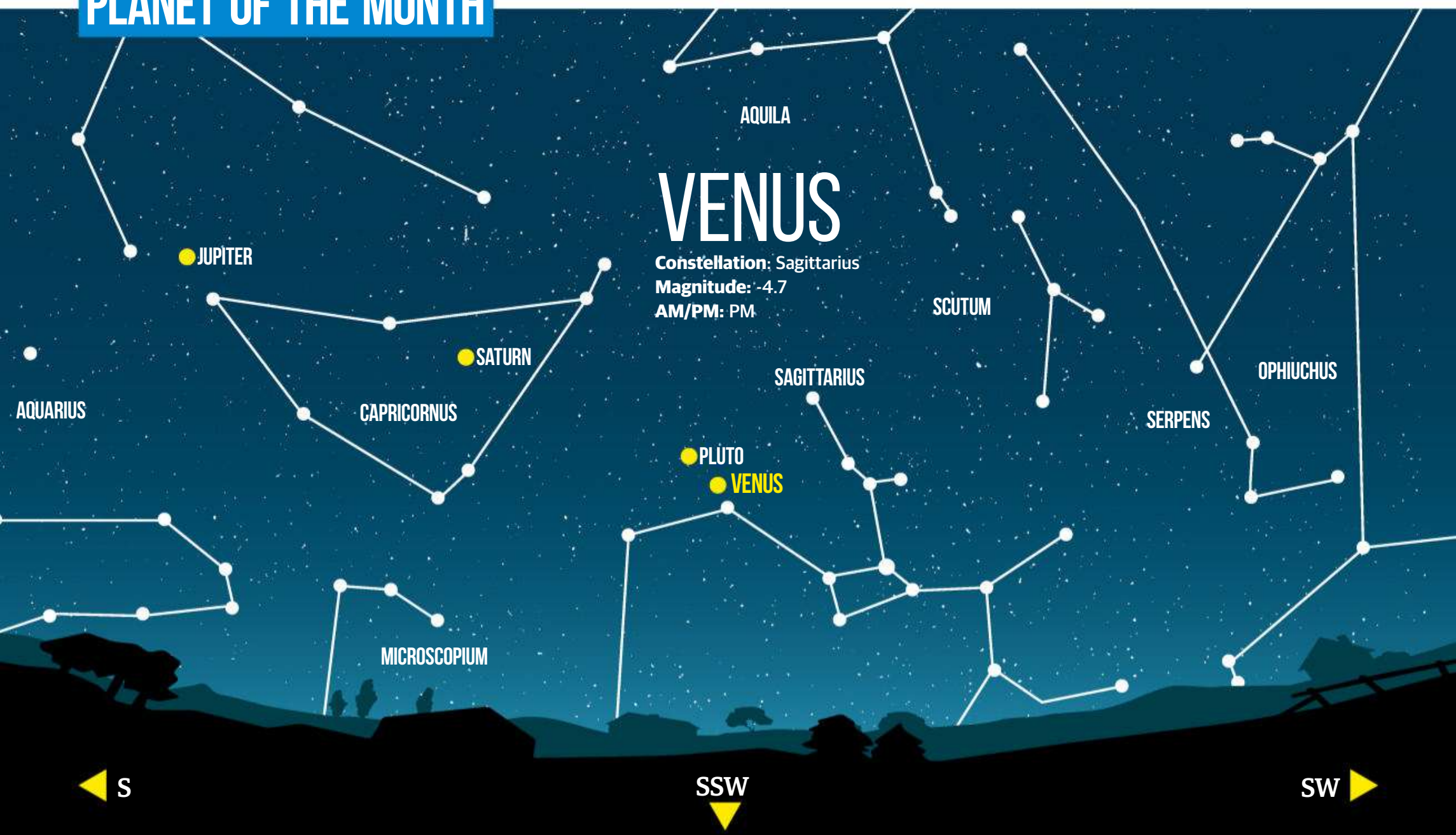
All rise and set times are given in GMT

DATE	RA	DEC	CONSTELLATION	MAG	RISE	SET
2 DEC	16h 38m 17s	-23° 07' 12"	Ophiuchus	-1.3	07:58	17:02
8 DEC	17h 18m 57s	-24° 38' 42"	Ophiuchus	-1.0	08:26	15:54
15 DEC	18h 07m 23s	-25° 25' 48"	Sagittarius	-0.8	08:53	16:09
22 DEC	18h 56m 01s	-25° 02' 15"	Sagittarius	-0.7	09:11	16:34
29 DEC	19h 42m 51s	-23° 24' 56"	Sagittarius	-0.7	09:17	17:03
2 DEC	19h 31m 42s	-24° 39' 12"	Sagittarius	-4.7	11:04	18:32
8 DEC	19h 43m 57s	-23° 29' 28"	Sagittarius	-4.7	10:44	18:29
15 DEC	19h 51m 58s	-22° 02' 05"	Sagittarius	-4.6	10:14	18:19
22 DEC	19h 51m 54s	-20° 34' 06"	Sagittarius	-4.6	09:37	18:00
29 DEC	19h 43m 16s	-19° 10' 57"	Sagittarius	-4.4	08:51	17:32
2 DEC	15h 17m 34s	-18° 01' 53"	Libra	+1.6	06:04	14:59
8 DEC	15h 34m 31s	-19° 07' 07"	Libra	+1.6	06:05	14:46
15 DEC	15h 54m 41s	-20° 16' 08"	Libra	+1.6	06:04	14:32
22 DEC	16h 15m 15s	-21° 16' 49"	Scorpius	+1.6	06:04	14:18
29 DEC	16h 36m 13s	-22° 08' 27"	Scorpius	+1.5	06:03	14:06
2 DEC	21h 51m 24s	-14° 05' 59"	Capricornus	-2.3	12:17	21:58
8 DEC	21h 54m 42s	-13° 47' 58"	Capricornus	-2.3	11:54	21:38
15 DEC	21h 58m 56s	-13° 24' 42"	Aquarius	-2.2	11:28	21:17
22 DEC	22h 03m 33s	-12° 59' 10"	Aquarius	-2.2	11:03	20:56
29 DEC	22h 08m 30s	-12° 31' 32"	Aquarius	-2.2	10:39	20:37
2 DEC	20h 45m 35s	-18° 51' 31"	Capricornus	+0.7	11:37	20:22
8 DEC	20h 47m 37s	-18° 43' 39"	Capricornus	+0.7	11:16	20:03
15 DEC	20h 50m 11s	-18° 33' 36"	Capricornus	+0.7	10:49	19:37
22 DEC	20h 52m 57s	-18° 22' 39"	Capricornus	+0.7	10:25	19:16
29 DEC	20h 57m 37s	-18° 03 '53"	Capricornus	+0.7	09:44	18:39

THIS MONTH'S PLANETS

Look out for a bright 'Christmas star' gracing the evening sky this holiday season

PLANET OF THE MONTH



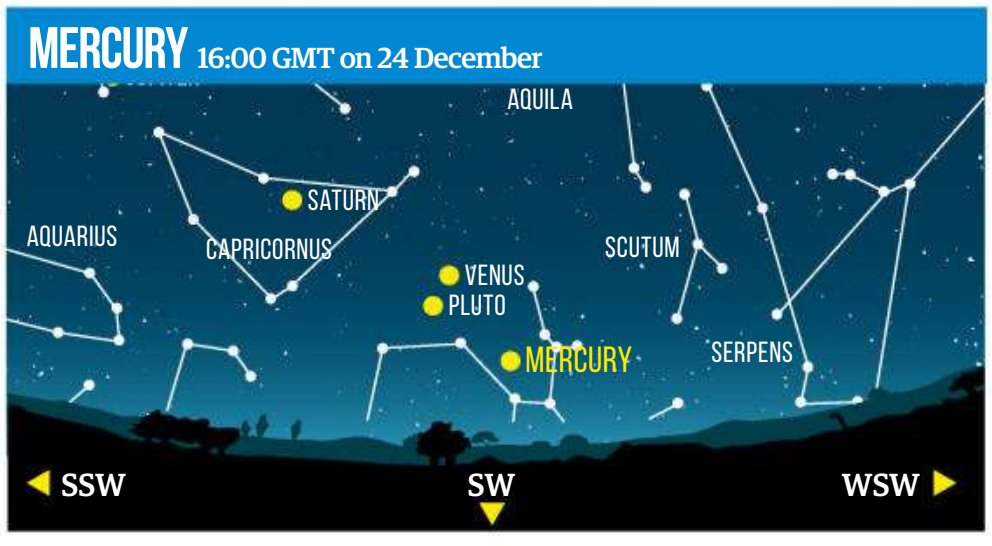
16:00 GMT on 4 December

Whether you're a panicking last-minute Christmas shopper or a cheering New Year reveller, you will be able to see a beautiful 'Christmas star' in the sky this month. Throughout December, Venus will be visible as a bright evening star, glinting in the south-southwest after sunset. It will become visible as a spark of silvery-white as soon as twilight begins to darken the western sky, and it will have company during the festive period – several other planets will be in the same part of the sky, and the Moon will drift past it as well.

Shining at magnitude -4.7, Venus will be brighter than every other planet and star in the sky, so bright that not even the light pollution which now blights so many of our towns and cities will prevent you from seeing it. Your naked eye will pick it out very easily, with the planet looking like a lantern above the trees, and the view through a pair of binoculars or a small telescope will be beautiful.

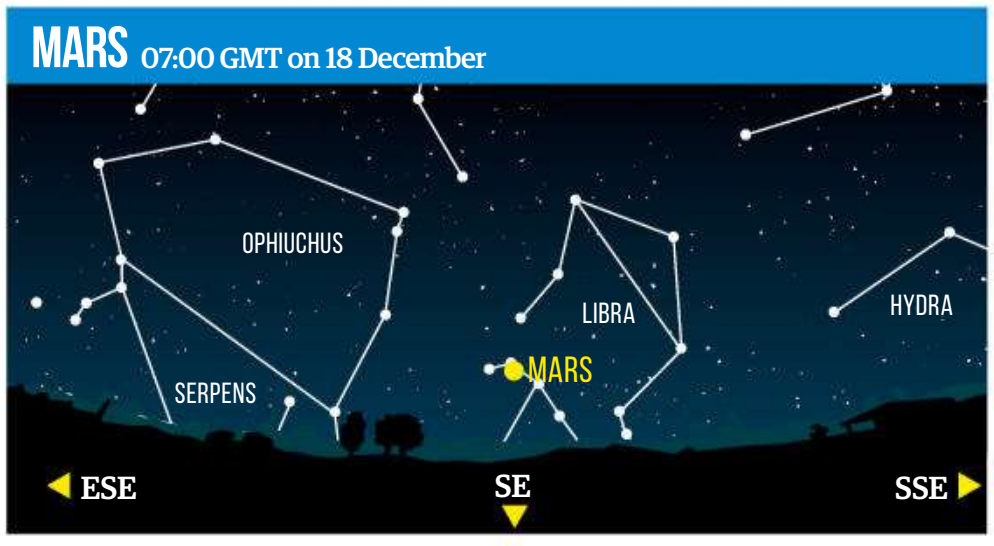
This month Venus will be visible from soon after sunset until several hours after it. You'll find it shining to the lower right of the pairing of Jupiter and Saturn, easily the brightest of the three. It will also have a very close encounter with Mercury at the end of the month; on 29 December the two worlds will appear just over four degrees apart in the sky, which should be a thrilling sight in binoculars and small telescopes. You should also look out for a lovely crescent Moon shining close to Venus in early December. After sunset on 6 December, the Moon will be found down to Venus' lower right, and the following evening will shine to its upper left.

Named after the goddess of love because of its incredible beauty, Venus is often nicknamed 'Earth's twin', but that's not a very accurate comparison. The only things the two worlds have in common are their size and physical composition. There are plans for astronauts to return to the Moon in 2024 and to travel to Mars within a decade after that, but people won't land on Venus for many years, if ever, so you should head out on these chilly December evenings and enjoy the sight of Venus blazing in the sky.



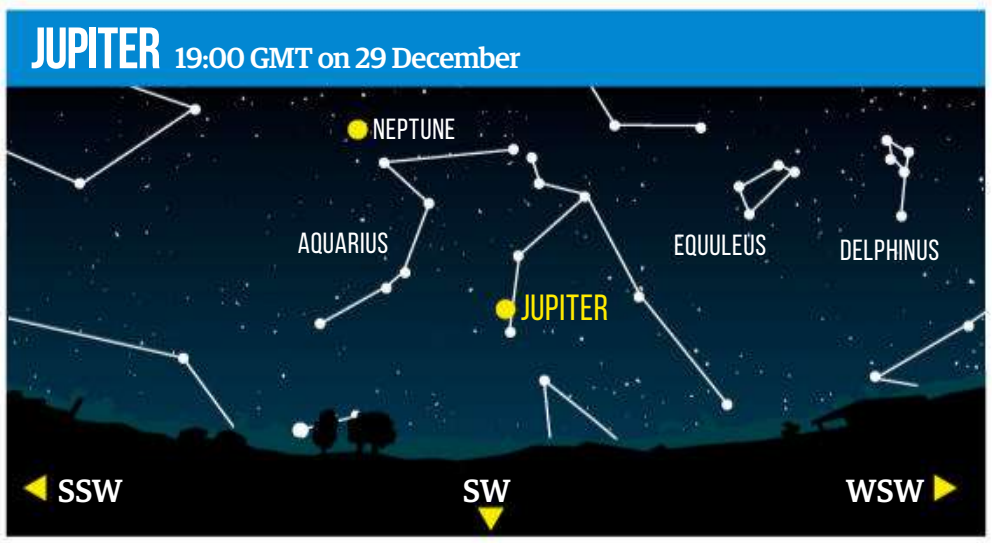
Constellation: Sagittarius **Magnitude:** -0.7 **AM/PM:** PM

At the start of the month Mercury is too close to the Sun to be visible, but as the days pass it will slowly pull away from it and begin to become visible in the evening twilight, sitting to the lower right of much brighter and higher Venus. Mercury will remain very low in the southwest during December, so low that any trees or buildings on your skyline will hide it.



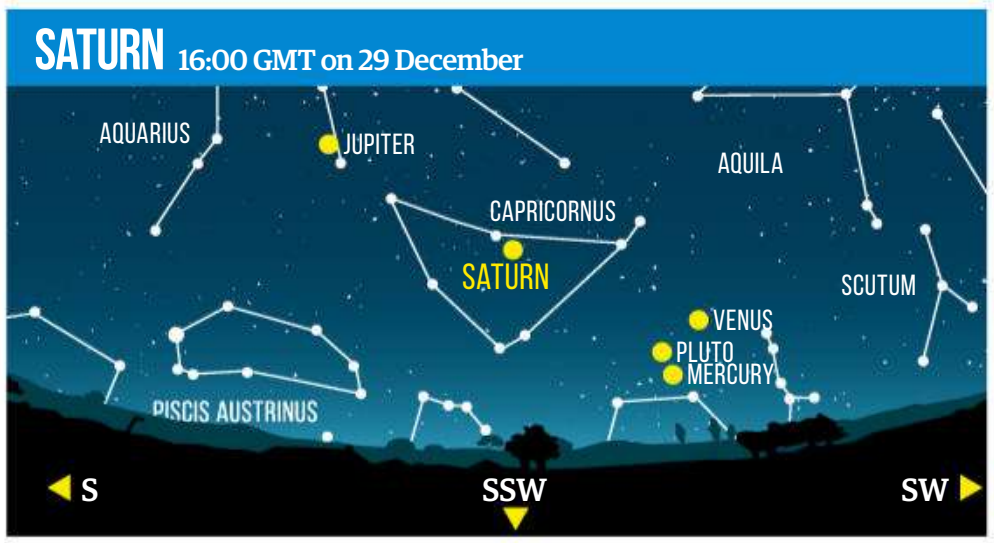
Constellation: Libra **Magnitude:** +1.7 **AM/PM:** AM

Mars observers have had a very challenging time recently, but the Red Planet's visibility will improve this month. At the start of our observing period the Red Planet will be a morning object, rising well over an hour before the Sun, and it should be easily visible to the naked eye until the morning twilight washes it out of view.



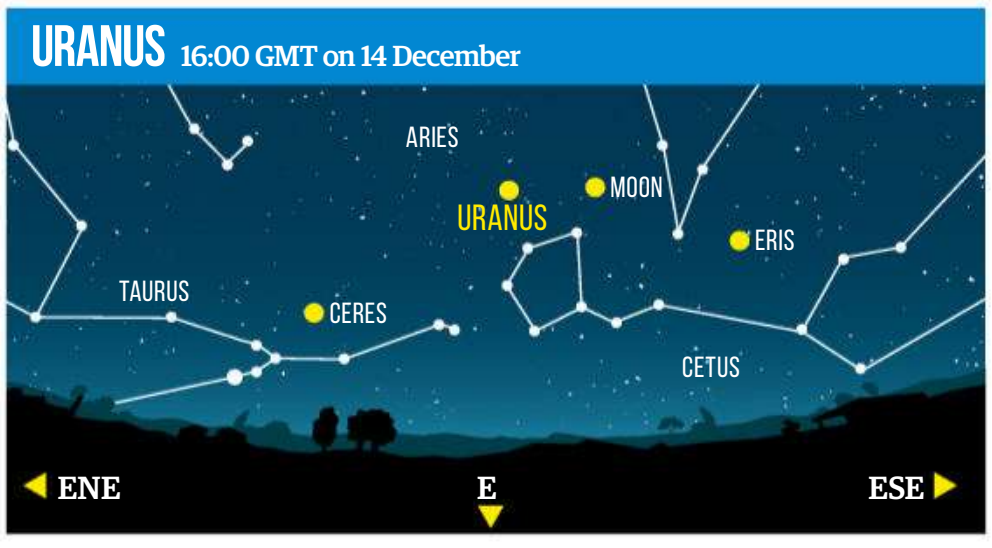
Constellation: Capricornus **Magnitude:** -2.2 **AM/PM:** PM

Jupiter is a gas giant world, and the largest planet in the Solar System. Through December it will be clearly visible to the naked eye as a bright blue-white star shining in the south as soon as the sky begins to get dark. At the start of December Jupiter will be visible from sunset until around 22:00, and by the end of December it will be setting an hour earlier.



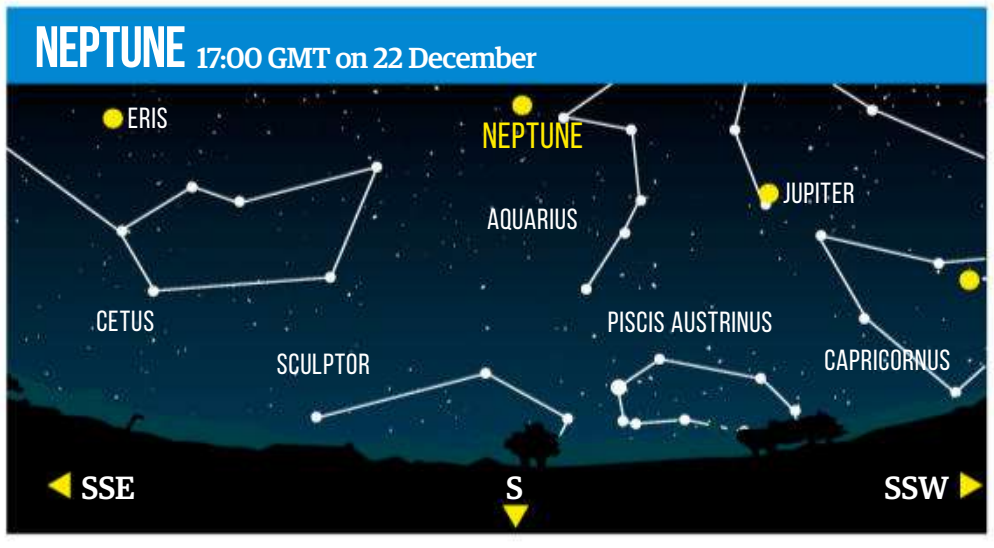
Constellation: Capricornus **Magnitude:** +0.7 **AM/PM:** PM

You'll need to be somewhere with a low and clear horizon if you want to see the famous Ringed Planet this month because it will already be quite low in the sky after sunset. However, like its larger, brighter neighbour Jupiter, Saturn will be easily visible to the naked eye, shining low in the south as soon as the sky begins to darken.



Constellation: Aries **Magnitude:** +5.7 **AM/PM:** PM

With a magnitude of +5.7, Uranus will technically be visible to the naked eye from Earth, but you'll only be able to see it with binoculars or a telescope because it will look like one little star among many others of the same brightness. This month Uranus will be visible all night, highest in the south around midnight and setting in the early hours.



Constellation: Aquarius **Magnitude:** +7.9 **AM/PM:** PM

Neptune is the farthest planet from the Sun; at this great distance it is far too faint to be visible to the naked eye, so you'll need binoculars or a telescope if you want to see it, and even then it will only look like a tiny, blue-green star. At the start of December Neptune will be visible from sunset until after midnight.

© NASA

MOON TOUR

EDDINGTON CRATER

Challenge yourself this month by locating one of the trickiest impacts on the lunar surface

Usually the lunar features we profile here are very easy to find, if not with the naked eye then at least through a pair of binoculars or a small telescope. They are large, bright craters; wide, dark seas or towering sunlit mountain ranges. This month's target is going to provide you with much more of a challenge: it's small, tucked away almost on the Moon's limb and so tricky to spot you probably won't find it the first time you look...

Eddington crater is named in honour of British astronomer Sir Arthur Eddington, one of the first astronomers to figure out the nuclear processes that take place in the hearts of stars. Born in the picturesque Lake District town of Kendal, Eddington was a contemporary of Albert Einstein, with the great physicist calling Eddington a genius. The author of many popular astronomy books and a regular radio broadcaster, Eddington spent a lot of time doing what we refer to now as outreach – it could be said that he was an earlier version of Professor Brian Cox.

He is perhaps best known for travelling to the island of Principe, off the west coast of Africa, in May 1919 to observe a total solar eclipse. During totality, Eddington observed stars which popped into view around the eclipsed Sun. By measuring how much their positions appeared to have shifted as their light was bent around our star, Eddington helped prove Einstein's famous general theory of relativity to be accurate.

Eddington crater is an impressive 125 kilometres (77 miles) wide and over a kilometre deep. If it was near the middle of the Moon's disc, it would be very easy to see, appearing larger than 'impact celebrities' like Copernicus and almost as large as Ptolemaeus. However, because the crater is very close to the lunar limb as seen from Earth, it's greatly foreshortened. It's also affected badly by libration, the rocking backwards and forwards of the Moon as it orbits Earth – sometimes it's pushed towards us, and appears larger, while other times it's pulled backwards and shrinks in size.

TOP TIP!

To find Eddington crater, use Oceanus Procellarum as your guide. The impact is a bay within this lunar mare, with the more prominent crater Seleucus resting to the east-southeast.

Whenever you look for Eddington, you'll see it looks more like an incomplete ring than a full circle, like most craters do. This is because it was flooded by a tsunami of molten lava many millennia ago. The tidal wave rolled up Eddington's southern rim and spilled down into it. This flooded the crater, burying its southern walls and any central mountain peak it might once have had, leaving behind a horseshoe-shaped remnant with a flat, dark floor. Only a handful of small craters now pock that dark floor, the largest of which is Eddington P, a mere 12 kilometres (7.5 miles) across.

To see Eddington this month you will almost certainly need a telescope, as only really powerful binoculars will spot it. Through a telescope's eyepiece, Eddington will look like a vertically stretched, grey-white horseshoe against the darker lunar surface, very close to the Moon's curved limb. Eddington isn't far from the much brighter and much more obvious rayed crater Aristarchus.

Being so close to the western limb, Eddington can only be seen when the Moon is at, or past, full. At the start of December, it's fully illuminated as the Moon rises in the evening sky. As the month progresses and a waning lunar phase slips into the morning sky, the terminator – the line between night and day – will sweep relentlessly towards the crater, covering it on 3 December. The impact will then remain unobservable until 18 December, when it will be bathed in the Sun's rays once more.

NAKED EYE & BINOCULAR TARGETS

There's a wealth of winter wonders to enjoy gazing at this December

AURIGA

1 Betelgeuse (Alpha Orionis)
Betelgeuse is a red supergiant star 650 times wider than our Sun. Shining at magnitude +0.56, it's the ninth-brightest star in the sky and lies 500 light years away. Astronomers have predicted that it will explode as a supernova one day, and will then shine brighter than the Moon.

2 The Pleiades (Messier 45)
One of the most famous and loved star clusters in the sky, the Pleiades is also known as the 'Seven Sisters' because its seven brightest stars can be seen with the naked eye, forming a 'mini Dipper' shape. Binoculars reveal it contains hundreds of glittering blue-white stars.

2

3

TAURUS

3 The Hyades (Melotte 25)
This distinctive V-shaped star cluster – representing the horns of Taurus, the Bull – is obvious to the naked eye. It has five naked-eye stars, but contains several hundred in total. The bright-red star Aldebaran is not a member of the cluster – it just lies in its direction as seen from Earth.

1

ORION

4 Orion Nebula (M42)
Probably the most famous nebula in the whole sky, Messier 42 is an enormous cloud of dust and glowing gas 1,400 light years from Earth. This stellar nursery can be seen with the naked eye alone, but is a beautiful sight in binoculars and small telescopes.

4

5

5 Rigel (Beta Orionis)
A blue-white supergiant star 8,600 light years from Earth, magnitude +0.28 Rigel is the seventh-brightest star in the sky and is diagonally opposite ruddy Betelgeuse. It is an amazing 40,000 times more luminous than our own Sun. Through binoculars it looks like a sparkling diamond.

Horsehead Nebula
(Barnard 33)

DEEP SKY CHALLENGE

ORION'S DEEP-SPACE TREASURES

The mighty Hunter has a horde of little-known treasures for you to track down and enjoy

As the year draws to a close, nights are often sparkling clear and still, and everyone enjoys setting up their telescope on the frosty grass and gazing in awe and wonder at the green-and-grey billows and swirls of the Orion Nebula. But Orion has much more to offer than just that 1,400-light-year-distant stellar nursery. In and around the Hunter there are more subtle, more challenging wonders to hunt down.

This month we will help you point your telescope towards objects famous and obscure. Most observers have heard of the Horsehead Nebula, but few have actually seen it – we'll help you track it down. We also have a beautiful double star and a nebula that is as puzzling as it is pretty.

When you head out to observe the sky this month, you'll find that the price of a cold, clear night is a dramatic reduction in your comfort level. You'll need to dress warmly, and make sure you take regular breaks from your eyepiece to move around and get warm again. If it's snowed during the day you might find that light pollution is worse than normal, as the light coming off streetlights and security lights bounces up off the snow and into the sky. Using a nebula filter or getting as far from your town or city as possible will help here.

Hubble's Variable Nebula (NGC 2261)

© NASA/ESA

Source: Wikipedia Commons © Ken Crawford

1 Hubble's Variable Nebula (NGC 2261)

This small, faint reflection nebula, roughly triangular or cone shaped, changes in brightness over the course of a few weeks, hence its name.

2 Lower's Nebula (Sh 2-261)

This wispy, oval-shaped nebula is so faint and has such a low surface brightness that seeing it clearly is reserved for the owners of large or very large telescopes. Any light pollution, haze or moonlight will wash it away.

3 Horsehead Nebula (Barnard 33)

Essentially just a small, dark notch silhouetted against a brighter background haze, seeing it requires a large-aperture telescope, a perfect sky, averted vision and usually a nebula filter.

4 The Flame Nebula (NGC 2024)

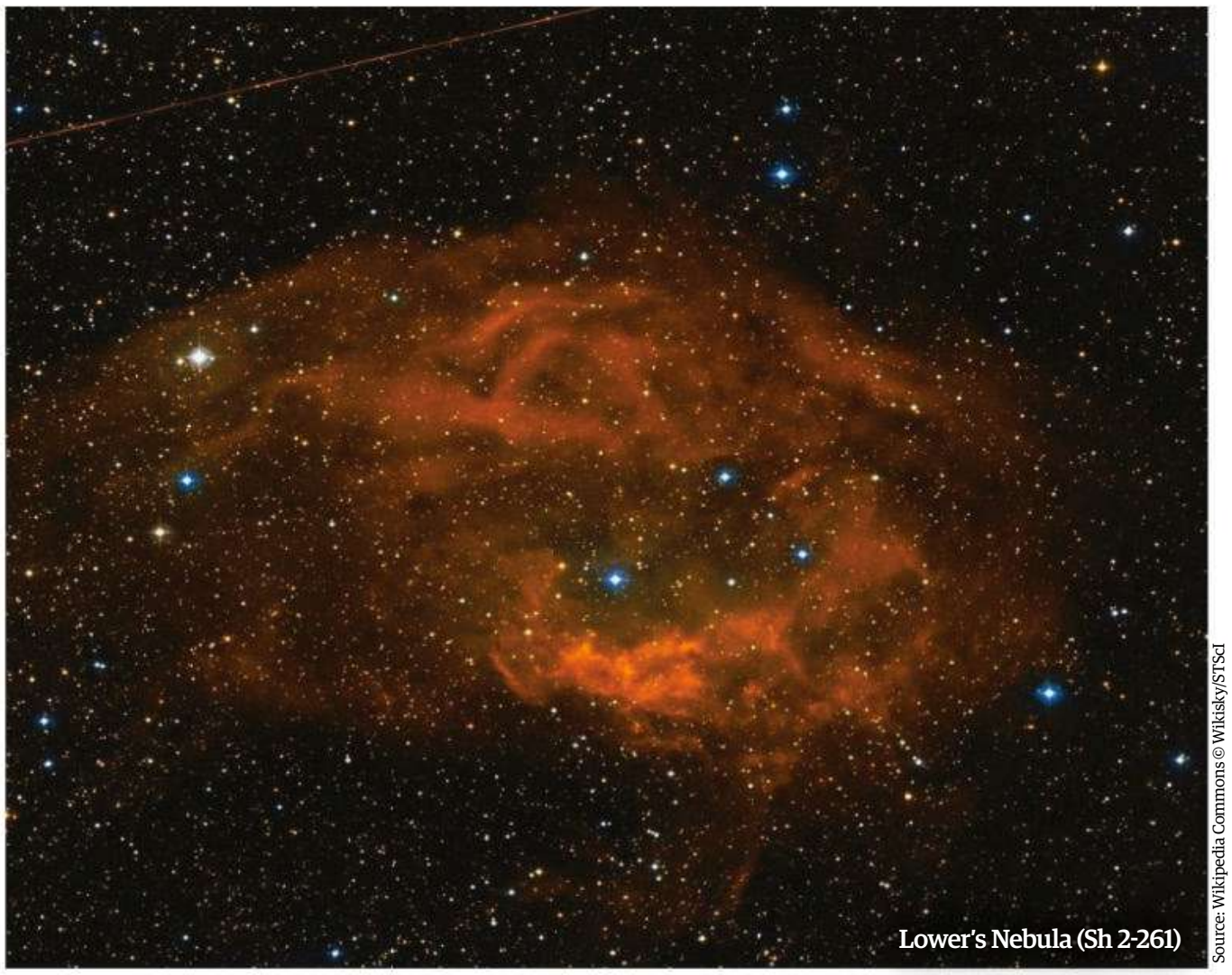
The tenth-magnitude Flame Nebula lies just to the west of bright star Alnitak (Zeta Orionis). The nebula will appear as a roughly cone-shaped glow cut through with darker bands.

5 Meissa (Lambda Orionis)

The brightest of the triangle of faint stars traditionally representing Orion's head, Meissa is a third-magnitude star with a magnitude +5.6 companion. The contrast between the brighter blue star and fainter star's white colour is striking.

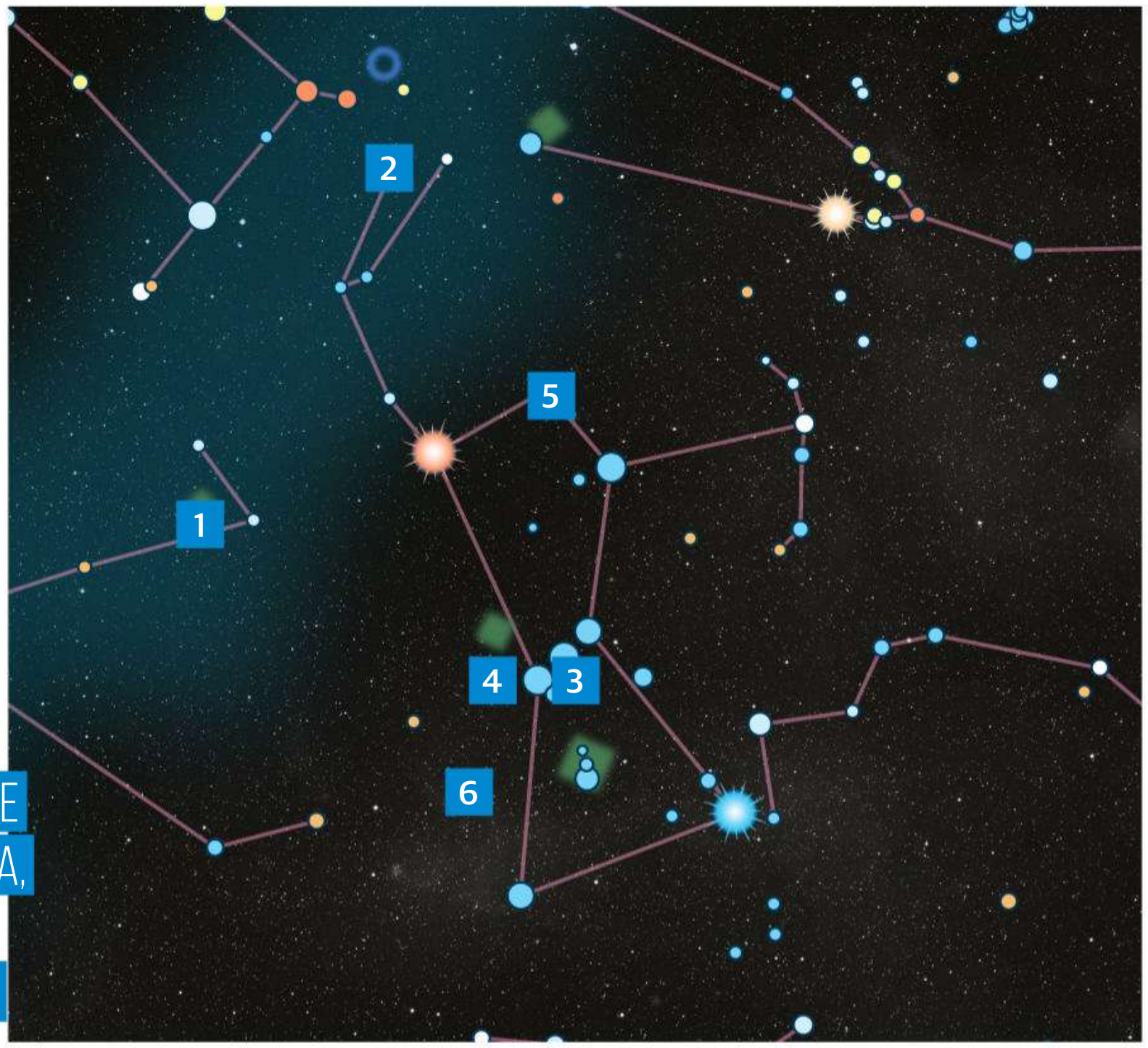
6 HD 38858

This star is worth gazing at because it's remarkable for two companions you won't see through any telescope. It's surrounded by a huge disc of comets and is orbited by a planet twice the mass of Uranus in its habitable zone.



Lower's Nebula (Sh 2-261)

Source: Wikipedia Commons © Wikisky/STScI



"MOST OBSERVERS HAVE HEARD OF THE HORSEHEAD NEBULA, BUT FEW HAVE ACTUALLY SEEN IT"

THE NORTHERN HEMISPHERE

There's an impressive array of targets to enjoy, including galaxies, nebulae and vibrant double stars

If you're a fan of splitting double stars with your telescope then head over to Aries (the Ram), which makes its appearance this month, bordered by the star patterns of Taurus (the Bull), Pisces (the Fishes) and Cetus (the Whale). In particular, binary star systems Lambda Arietis, Epsilon Arietis and Mesarthim are splendid targets to resolve for astronomers with medium to large-sized telescopes. Meanwhile, orange giants Hamal (the Head of the Ram) and Botein (Little Belly) can be picked out using nothing more than the naked eye. Orion (the Hunter) is also prominent in the December skies, featuring red supergiant Betelgeuse, De Mairan's Nebula (Messier 43) and the stunning Orion Nebula (Messier 42).

USING THE SKY CHART

This chart is for use at 22:00 mid-month and is set for 52° latitude.

1. Hold the chart above your head with the bottom of the page in front of you.
2. Face south and notice that north on the chart is behind you.
3. The constellations on the chart should now match what you see in the sky.

MAGNITUDES

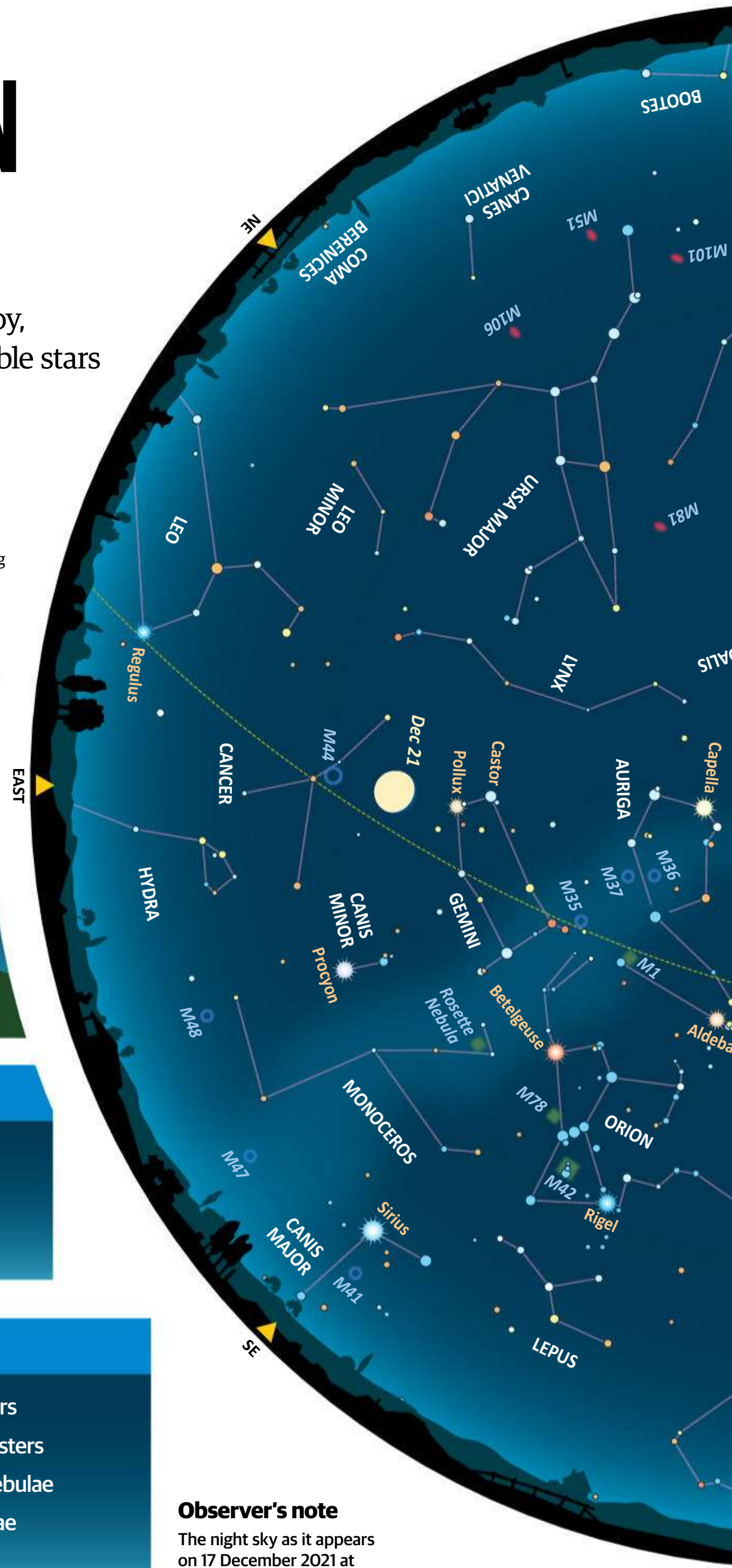
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 2.5
- 2.5 to 3.0
- 3.0 to 3.5
- 3.5 to 4.0
- 4.0 to 4.5
- Fainter
- Variable star

SPECTRAL TYPES

- O-B
- A
- F
- G
- K
- M

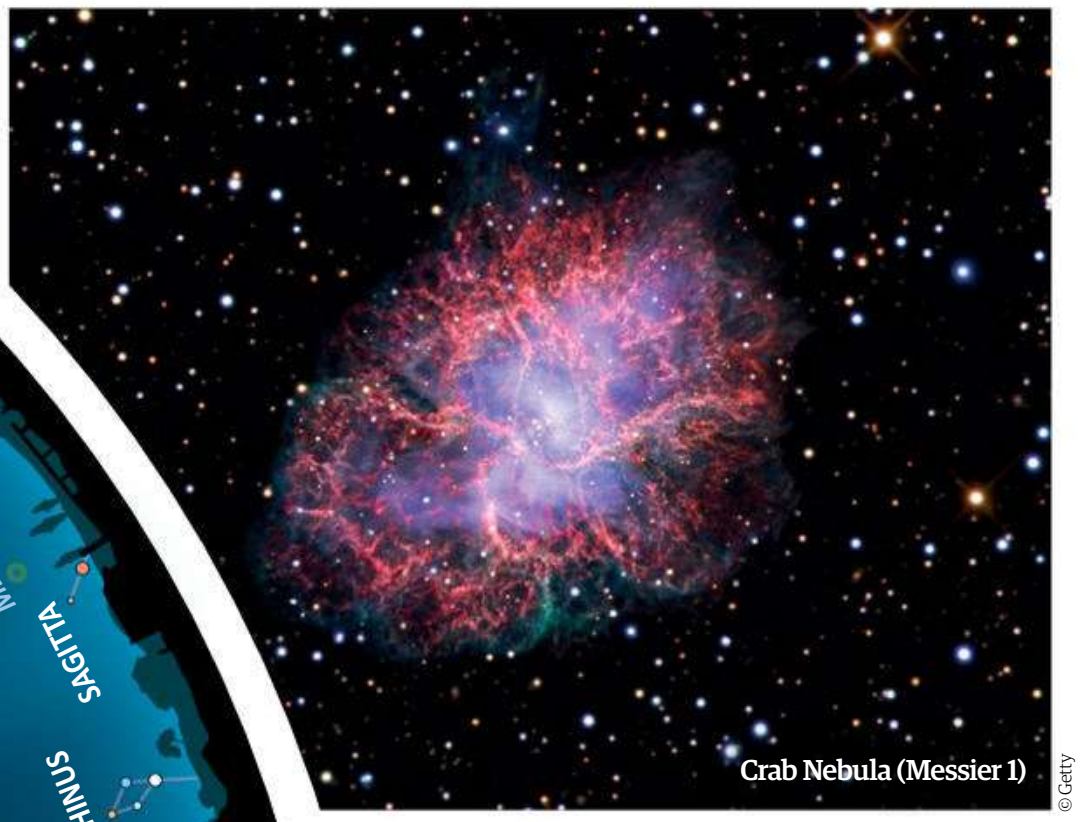
DEEP-SKY OBJECTS

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies

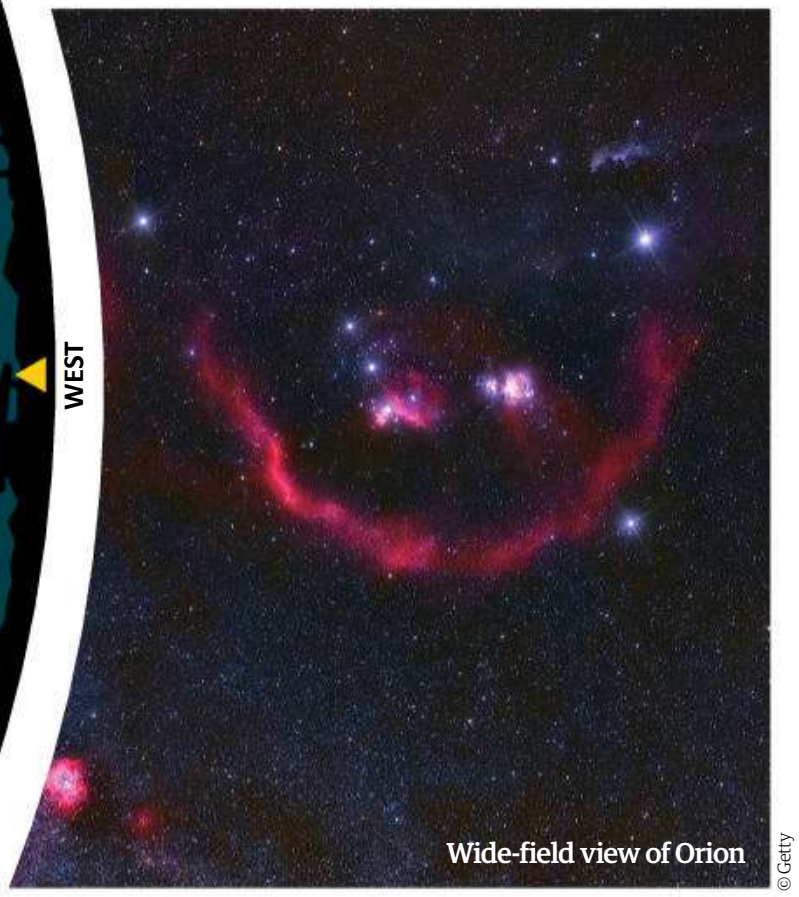


Observer's note

The night sky as it appears on 17 December 2021 at approximately 22:00 (GMT)


Crab Nebula (Messier 1)

© Getty


Wide-field view of Orion

© Getty

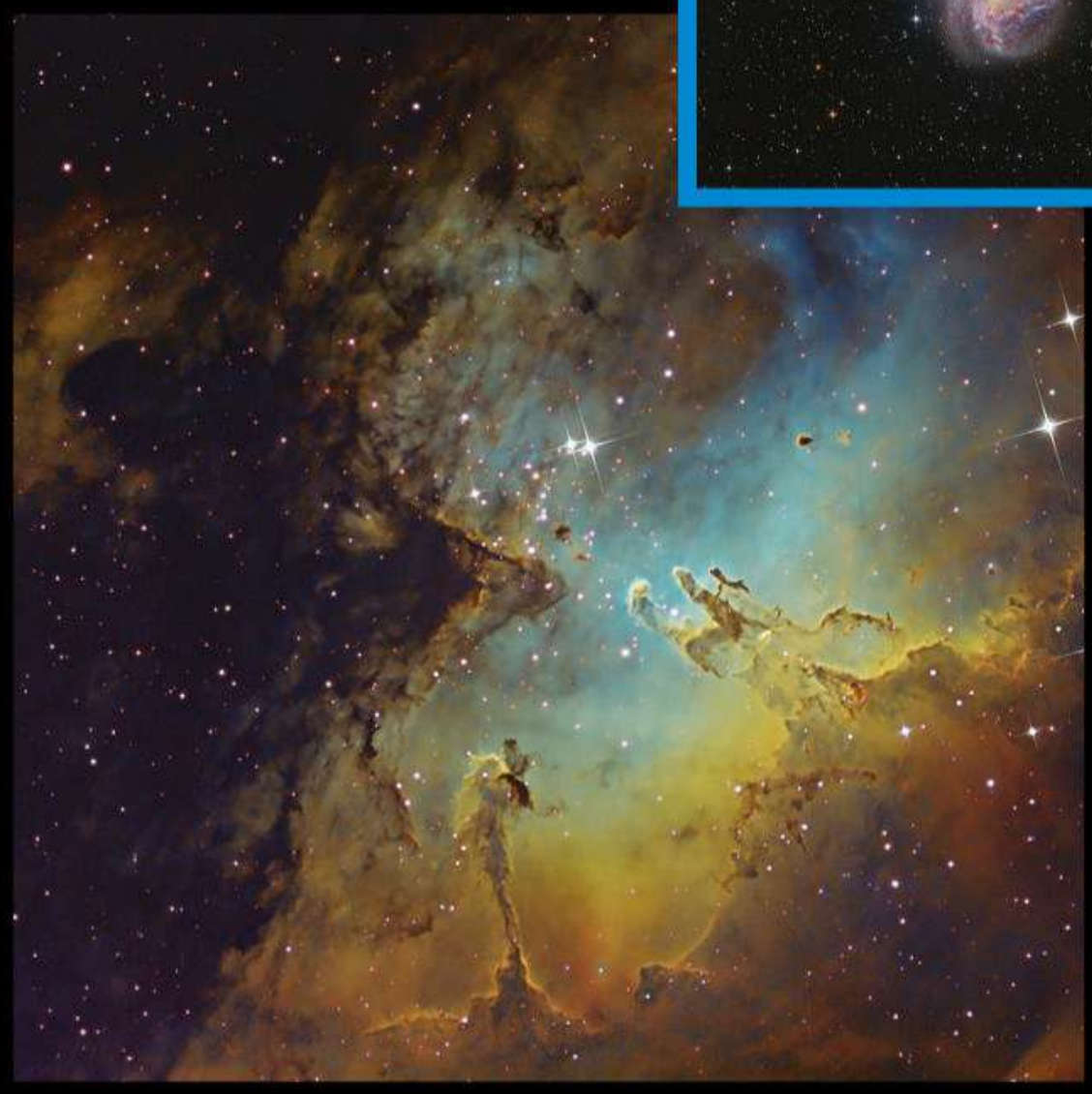
Messier 74

© Getty

STARGAZER

ASTROSHOTS OF THE MONTH

Get featured in **All About Space** by sending your astrophotography images to **space@spaceanswers.com**



Terry Hancock

Location: Michigan

Telescope: 12" Ritchey-Chrétien reflector and Takahashi E180 astrograph

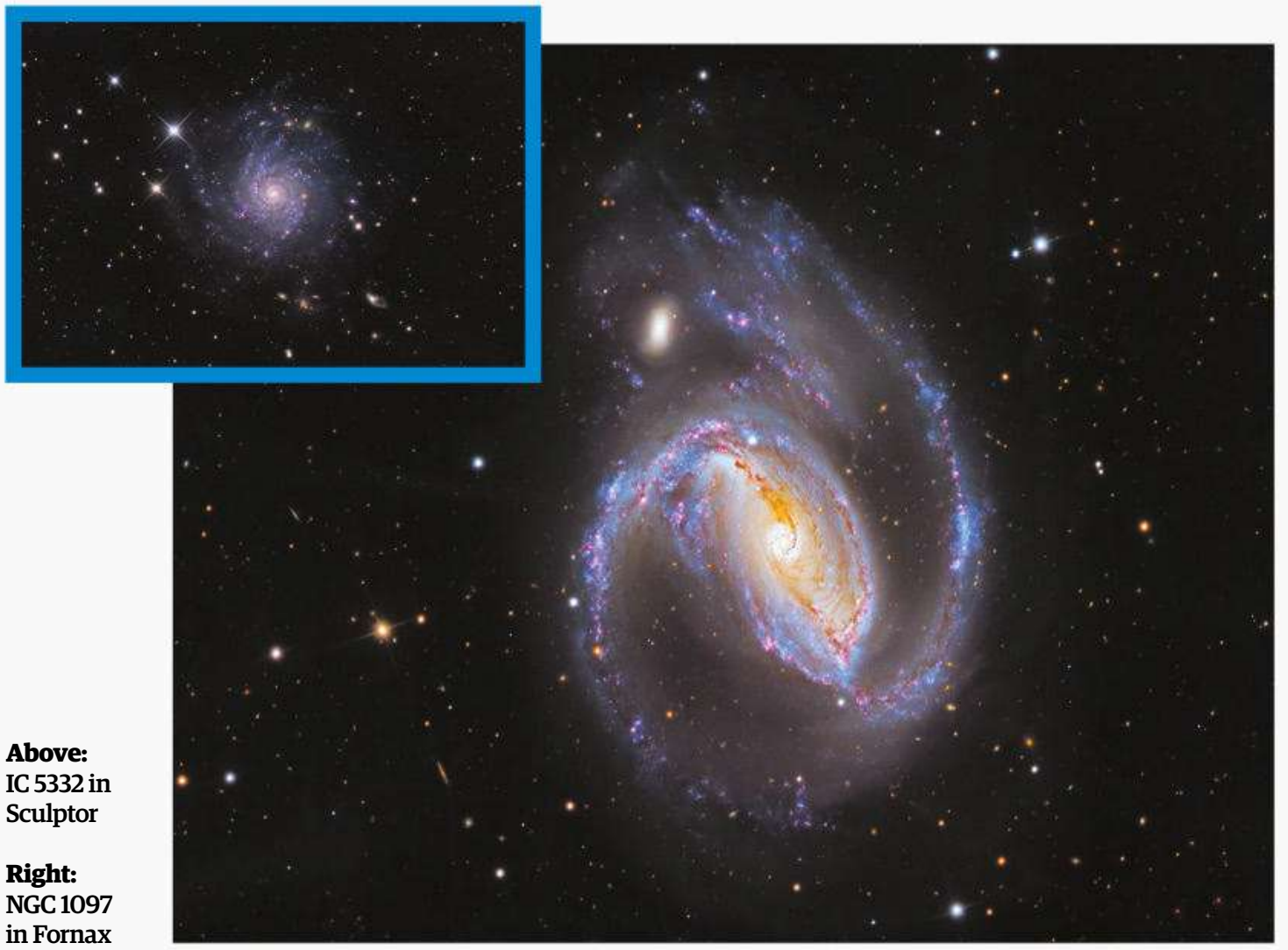
"My interest in astronomy and photography began some 40 years ago in Australia. Inspired by Sir Patrick Moore, my first telescope was a 4.5-inch Newtonian, and I enjoyed many nights in the pollution-free night skies of the hot Australian outback. It was often so dark that the Milky Way cast a shadow on the ground. The skies are mediocre in western Michigan where I observe from these evenings. I pride myself in taking really long exposures of deep-sky objects and always try to maintain a natural look."

"IT WAS OFTEN SO DARK THAT THE MILKY WAY CAST A SHADOW ON THE GROUND"

Main: Gamma Cygni region in the constellation of Cygnus

Above: The Southern Pinwheel Galaxy (Messier 83) in the constellation of Hydra

Left: Pillars of Creation in the Eagle Nebula (Messier 16)



Warren Keller

Location: West Virginia

Telescope: 16" RCOS Ritchey-Chrétien owned by the University of North Carolina

"I'm an advanced astrophotographer and teacher and have been published as an author and photographer in many astronomy magazines, as well as many places on the internet, including NASA's Astronomy Picture of the Day (APOD).

"I have also been a consultant for Celestron, where I codesigned AstroFX software for the Nightscape camera. And I'm now a part-time representative for QSI Imaging."

Above: IC 5332 in Sculptor

Right: NGC 1097 in Fornax

High-contrast view of lunar craters and mare

Jay Hawkins

Location: St Ives, Cambridgeshire, UK

Telescope: Celestron NexStar 8SE

"My interest in astronomy has been going for about 11 years, since my dad bought me my first telescope. I love every minute of observing the night sky – it never fails to amaze me. Being able to point my telescope out of my bedroom window and see the Moon in such detail is breathtaking. I keep an eye out for meteor showers, which are another beautiful way to see astronomy in action using just the naked eye. Recently, I've been taking photographs of stars when they are at their brightest, which is utterly amazing."

REVIEW

CANON EOS RA

This DSLR gives astrophotographers and landscape photographers everything they need to capture the colours in their work

Reviewed by Ollie Taylor

CAMERA ADVICE

Cost: £2,599.99 / $2,499.99
From: Canon
Type: Mirrorless
Kit lens: N/A, sold with or without EF converter
Sensor: 30.3 megapixels
Lens mount: RF, but can use EF with a converter
ISO range: 100 to 40,000 (50 to 102,400 expandable)
Viewfinder size/resolution: 3.2" 3.69M-dot OLED
Video capability: 4K
Weight: 660 grams
Size: 13.4 x 9.9 x 8.3 centimetres
Memory card type: Single SD

BEST FOR...

£ LARGE BUDGETS

! SERIOUS ASTROPHOTOGRAPHERS

WIDE-ANGLE PHOTOGRAPHY

SOLAR SYSTEM

DEEP SKY

x3 Images © Canon

Astrophotographers and landscape photographers looking to try and emphasise the colours of the nebulae in their work now have a serious piece of kit available to help them achieve this in the Canon EOS Ra. Differentiating from dedicated astrophotography cameras normally used on telescopes, the Canon EOS Ra interlinks the rest of Canon's RF mirrorless system, resulting in an array of interchangeable lenses. With a familiar feel for existing EOS R users, the camera is essentially a Canon EOS R with some adjustments, meaning the unit doubles up nicely as a second camera for nightscapers who use two units.

The EOS Ra also doubles up for everyday use for those only using one camera who have a predominant interest in the night sky – albeit with a few notable minor colour casts here and there. However, it makes it an attractive product, being a multipurpose unit with which users can easily take daytime shots and later venture to dark-sky sites to really put the Canon EOS Ra through its paces.

The Canon EOS Ra is a camera that has been designed specifically for astrophotographers, though it can also be used for everyday photography due to Canon's in-camera white balance firmware.

Astrophotographers like to be able to capture the magenta colour in nebulae when shooting deep-space objects. More recently, landscape astrophotographers have also started to implement the colour from nebulae within their nightscape scenes. The problem is that 'off-the-shelf' interchangeable-lens cameras have filters over the sensor that purposely block out the colours at this end of the spectrum, created by the gasses within nebulae, alongside blocking multiple other wavelength values to create a clean, natural-looking image. This is because allowing these wavelengths to penetrate the sensor causes obscure colours and unwanted ghosting, halos and banding due to multiple sources emitting different unwanted wavelength frequencies.

The EOS Ra is currently the only full-frame mirrorless camera manufactured for greater sensitivity to colours at the red end of the spectrum, with the predominant aim to capture more 656.28-nanometre (nm) Hydrogen-alpha. Canon has also taken into consideration how astrophotographers and landscape astrophotographers focus at night using manual focus and refine their focus by magnifying on a star. Considering this, Canon has created a 30x focus magnifying mode, allowing much easier fine-tuning and star sharpness precision.

Naturally, the Canon EOS Ra follows the general design and ergonomics of the EOS R series of mirrorless cameras, and apart from the 'Ra' written on the body, there's very little to distinguish it from the Canon EOS R. The Canon EOS Ra is compact and stylish, with sleek angular curves and button positioning.

When first picking up an EOS Ra from either a traditional Canon DSLR or another brand of DSLR or mirrorless, the positioning of dials, buttons and the general handling can seem a little strange. However, this is soon overcome, and it doesn't take long to adjust and realise that the camera's layout is both unique and logical. Your hands are soon at ease with it and its smaller, lightweight design, and its handling quickly becomes the norm – so

Left: A stylish camera with a solid body

Left: The EOS Ra is compatible with many Canon RF lenses

Below: The camera is well suited to astrophotography in all wavelengths

"USERS CAN EASILY TAKE DAYTIME SHOTS AND LATER VENTURE TO DARK-SKY SITES TO REALLY PUT THE CANON EOS RA THROUGH ITS PACES"

much so that picking up another camera soon after feels alien. The compatible Canon RF lenses also have a customisable control ring on the front of the lens, allowing this to be changed to aperture, shutter speed, ISO and so on to add more flexibility to camera customisation.

The handgrip is a generous size and comfortable, though the digital mode button within the typical shutter speed dial can take some getting used to, and the multifunction bar to the right of the viewfinder can get in the way for those with larger hands. But if necessary, multifunction bars can be switched off. The Canon EOS Ra is weather-sealed, though not to the extent of traditional DSLRs such as the Canon 5D Mark IV.

The customisation is a little limited compared to some other brands, though assigning general functions to buttons or dials is simple. The typical AF-ON and AEL buttons can be converted to adjust ISO or other commands by holding the button and adjusting the dial. ISO button customisation is somewhat essential for general ease of use while gripping the camera in the dark, as opposed to relocating half of your hand and searching for a back or top-located ISO button. The quick menu, however, is non-customisable, thus a few of the menu options you may want to switch over cannot be done, forcing you to customise another button.

Aside from the H-alpha sensitivity, one of the key selling points for astrophotographers is the 30x focus magnification, making focusing through a telescope easier than the typical 10x magnification. This is also useful for landscape astrophotographers and low-light photographers, especially when focusing on subjects such as the Moon's surface. It does make focusing on duller stars with wide lenses easier, though sometimes you do find yourself switching back to 10x magnification with brighter stars.

STARGAZER

Right: The sensor is specially designed to pick up magenta hues

© Canon

When coupled with the Canon EOS Ra, fast lenses allow for autofocus to be used on stars in the dark as long as they can be seen clearly. You can simply autofocus on a bright star, then turn the autofocus off, and this even works with wide-angle lenses.

Canon's touchscreen system is nothing short of perfect: it's a system that actually makes you want to use it due to how fluent it feels and the ease of controlling the camera using it, which isn't the case with some other mirrorless brands. The LCD rotates 360 degrees once flipped out from the body; this is highly advantageous, as for astrophotography the camera is often at obscure angles, meaning you can have the screen facing your viewing position and control the camera from the touchscreen. But there is one big downside to the screen design. Landscape astrophotographers usually favour L-bracket plates to hold their cameras, and these get in the way of the LCD being able to flip out, and therefore rotate.

The Canon EOS Ra is the first 35mm equivalent digital camera designed specifically with astrophotographers in mind since May 2015 and the legendary Nikon D810A. Purchasing this unit is almost a no-brainer for astrophotographers, though there is the matter of conversions and where these fit in. A conversion essentially means removing the 'hot mirror' sensor that filters infrared and ultraviolet; many companies replace it with their own infrared cut and H-alpha-enhancing filter to allow focus to work. When it comes to landscape astrophotography, conversions usually cause stars to stretch around the edge of the frame. With Canon designing the EOS Ra with both astrophotographers and landscape astrophotographers in mind, there's no stretching of the stars with wide-angle lenses.

Canon's reworking of the sensor filters in the EOS Ra doesn't disappoint; it clearly picks up the indicated 4x H-alpha frequency so nebulae can be seen in the imagery created using it. However, these colours are not usually visible straight from the camera; when shooting landscapes at night, RGB post-production techniques are often required to extract the data. Tracking landscape astrophotography on the Canon EOS Ra also helps capture more data, increasing the intensity of nebula colour within the image. These advanced techniques are factors that may put less experienced landscape astrophotographers off purchasing the Canon EOS Ra.

The 30.3-megapixel sensor easily holds its own, though it's difficult to understand why Canon rushed this out with a fairly old sensor, easily beaten with regards to overall landscape astrophotography image quality by cameras such as the Sony Alpha 7 III, Nikon Z6, Z7 and D850.

High-ISO images are cleaner out of the aforementioned cameras. Landscape astrophotographers usually track or stack for the sky, then create a long exposure for the foreground at a lower ISO to generate a cleaner image; the Canon EOS Ra just lags behind a little on overall image rendition, ISO grain and foreground detail for long exposures.

Six months later Canon released an incredible low-light performer in the EOS R6 with only 20.1 megapixels; it's well documented that the lower the megapixel count, the better real-world low-light performance in the field is with current sensor technology. It's a real shame that the EOS Ra didn't capitalise on using the R6 sensor, as this would have made it a serious landscape astrophotography powerhouse.

The battery life of the Canon EOS Ra is reasonable – even better with the LCD brightness turned down or off while shooting. Two or three fully charged LP-E6NH batteries should easily last most landscape astrophotographers a full night of shooting with the unit.

Another plus side to the EOS Ra is its little-known built-in software which shifts the white balance to an almost-normal tone when using the camera for purposes other than at night. The software is excellent, and although tints may be slightly different on certain colours within a scene, the built-in white-balance-shift software does an impressive job at making the RAW files look as if they have come out of a standard camera not designed for astrophotography, a feature impossible to replicate on a third-party conversion.

The Canon EOS Ra has another problem, though not one well documented, as the majority of deep-sky astrophotographers use multiple external filters and therefore filter out the problem. The EOS Ra can cause magenta halos on bright objects such as bright stars and planets, especially Mars and the Sun if shooting in the day. It's thought this is due to the camera allowing light in from the far end of the wavelength spectrum, past 656nm and towards the 700nm end.

Overall, the Canon EOS Ra is an excellent first-choice camera for deep-space astrophotographers, and should definitely make the grade as a second camera for landscape and nightscape astrophotographers who understand RGB editing and how to use trackers and advanced techniques to get the best from the device. However, it's definitely not an ideal all-around choice for a solo multipurpose camera for those with only a slight interest in astrophotography and landscape astrophotography.

FOR

- ⊕ H-alpha sensor sensitivity
- ⊕ 30x focus magnification
- ⊕ Brilliant aesthetics and ergonomics
- ⊕ User-friendly touchscreen and LCD
- ⊕ RAW file white balance firmware

AGAINST

- ⊖ Low-light and high-ISO performance could be better
- ⊖ Possibility of red halos and ghosting
- ⊖ Price of RF lenses
- ⊖ Only one memory card slot

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LIFE'S LITTLE MYSTERIES

Life is full of little mysteries. Can we learn things while we dream? Can animals predict earthquakes? Will Earth's continents ever reform into one supercontinent? What exactly are Saturn's rings? You'll find the answers to these, and many more questions, inside these pages. Whether you're curious about the human body, animals, the world around us or the secrets of science, technology and the universe, you'll find a treasure trove of questions that you've always wanted to know the answers to. From black holes to bison, there's a wealth of amazing answers ready for you to discover. Packed with incredible information, this bookazine will give you all the answers you ever wanted.

AMAZING ANSWERS TO CURIOUS QUESTIONS

If you're curious about the world we live in, you've come to the right place! If you've ever questioned how YouTube works, what would happen if two planets collided or what airless tyres are, this is the book for you. Inside you'll discover answers to the most mind-boggling questions. How long can animals live? Why are rain clouds grey? What is inside of a bird's egg? What are the laws of thermodynamics? What is the blood-brain barrier? What if we cut down all the trees? What is a cosmic catastrophe? What are white holes? What animals have been to space? What are the origins of espionage? What is the Tesla coil? What did it take to become a knight? Find all these answers and more.

SPACE EXPLORATION

Rewind the clock back to the 1950s and relive the first brave forays into space exploration with the likes of Sputnik before moving into the Space Age. Look back on iconic white-knuckle missions such as the Apollo 11 Moon landing, with special insight from Buzz Aldrin. Inside you'll also uncover some of the universe's most beautiful sights, thanks to the Hubble Telescope, and look at the intrepid Voyager probes as they journey further into interstellar space. You'll examine the technology that drives space exploration, such as spacesuits, rocket science and more, before touching on the more current innovations in the field today, as well as our fascination with Mars.

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CHRISTMAS GIFT GUIDE

With the holiday season just around the corner, **All About Space** selects presents that are sure to delight any space fan

FOR YOUR HOME

FLOATING 3D MOON NIGHT LIGHT LAMP

Cost: £182 ($239.97)

From: encalife.com

1 Guaranteed to make an impact in any room, this light harnesses magnetic-levitation technology to produce a Moon that looks like it's floating in mid-air. The light is finished with a realistic lunar texture and measures 14.5 centimetres (5.7 inches) in diameter. With three Moon colours to choose from, whether it be a warm, yellow glow or a crisp Moon white, there's a setting to suit every mood. The sleek design incorporates a simple touch switch on the base, requiring nothing more than a tap to bring the magic of the Moon into your home.

FOR STOCKING FILLERS

CONSTELLATION SOCKS

Cost: £10 (approx. $13.45)

From: shop.rmg.co.uk

2 What do you buy someone who has everything? Constellation socks! These stellar accessories will add a touch of cosmic flare to any wardrobe. The star-studded socks include many well-known constellations, including Orion and Ursa Major. Made from 63 per cent cotton, 35 per cent polyester and two per cent spandex and fitting shoe sizes 7 to 13, these socks are the perfect gift for the space lover in your life. Also, proceeds from sales made on the Royal Museums Greenwich online shop help to support the work of the museum.

FOR OBSERVERS

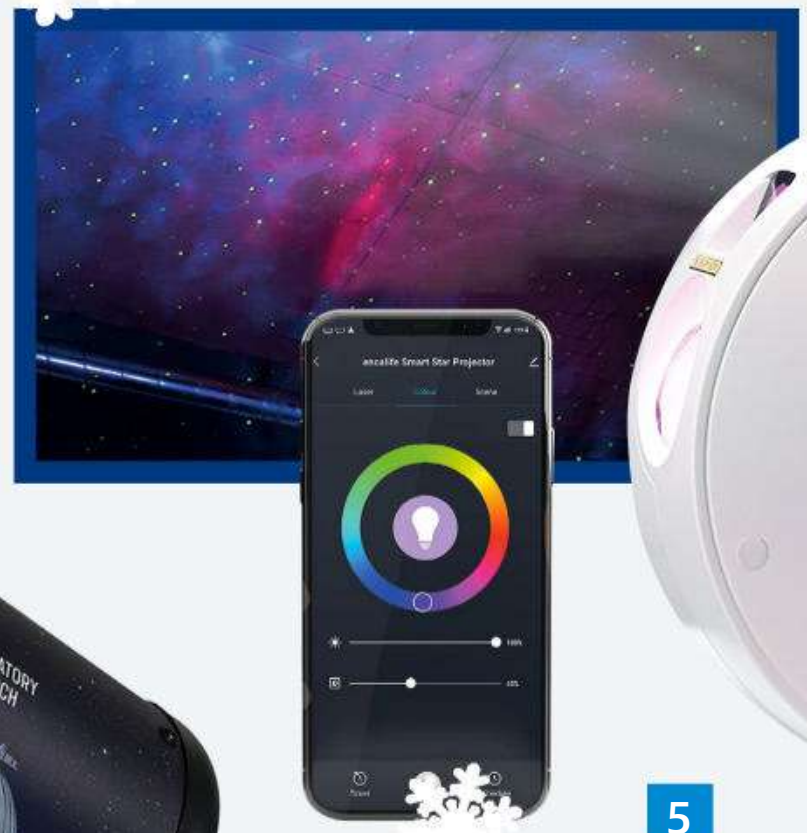
NIGHT SKY ALMANAC: A STARGAZER'S GUIDE TO 2022

Cost: £9.99 / $16.95

From: HarperCollins

3 Follow the progress of constellations through the seasons with this beautiful companion to the night sky. With the aid of easy-to-understand monthly calendars and maps, you will chart the rhythm of the lunar phases, discover events that light up the sky for brief periods and explore the rich tapestry of characters that adorn the starry canvas overhead. Written by astronomical experts and approved by the Royal Observatory Greenwich, the *Night Sky Almanac* is the perfect gift for amateur and seasoned astronomers.

4



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"IT'S CAPABLE OF FANTASTIC VIEWS OF THE MOON, BRIGHTER PLANETS AND STARS"

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4 Perfect for the budding astronomer, Celestron has partnered with Royal Observatory Greenwich to create this easy-to-use tabletop telescope. The 76mm reflector's optical tube is capable of fantastic views of the Moon, brighter planets and stars, and has been paired with a simple-to-use Dobsonian tabletop mount. Everything needed to get started is included in the gift box, including the ready-assembled telescope and two eyepieces: a wide-field 15x view and a magnified 75x for closer observations.

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FOR BOOKWORMS

THE RED PLANET: A NATURAL HISTORY OF MARS

Cost: £14.99 / $26.95

From: Waterstones

6 Uncover the wonder of Mars with planetary geologist Simon Morden. From the latest research and data from Mars probes to theories of planetary geology and the debate of life on Mars, *The Red Planet* takes you on an enthralling journey. Morden has a PhD in geophysics and has coauthored several scientific papers, though his award-winning writing career stems from his fiction writing. Therefore *The Red Planet* is an impressive scientific account of the history and geography of Mars, presented with true storyteller flair.

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JAMES 'JIM' LOVELL

A space veteran who completed four impressive missions, including the ill-fated Apollo 13

A retired NASA astronaut who flew on Gemini and Apollo missions, Lovell is most famous for his role as commander of the ill-fated Apollo 13. At the time of the mission, Lovell had spent more time in space than anyone in the world, and in total logged over 700 hours in space.

Lovell was born in Cleveland, Ohio, in March 1928. He developed an interest in rocket science as a high school student and went on to study engineering at the University of Wisconsin. Lovell then attended the United States Naval Academy, where he graduated with a bachelor of science degree in 1952.

In 1958, Lovell graduated from the Navy's test pilot school, spending the next several years testing fighter aircraft and other jets. The Navy's test pilots were among the best aviators in the country, and as such were prime candidates for NASA's astronaut program in the early 1960s.

Lovell was selected as a potential astronaut candidate for Project Mercury, but was turned down because of a temporary excess of a protein called bilirubin in his blood, which could have been indicative of a liver problem. But he got a second chance when NASA began recruiting astronauts for the Gemini and Apollo programs. Lovell was selected in 1962.

Lovell served as a backup pilot for Gemini 4 before being assigned as one of two crew members on Gemini 7, which launched on 4 December 1965. The Gemini 7 flight was an endurance mission in every sense of the word. Lovell and Frank Borman spent more than 330 hours (nearly two weeks) in a spacecraft about the size of a coat closet. The men carried out nearly 20 experiments and operated without their spacesuits on for the first time. They also successfully rendezvoused with Gemini 6A on 15 December 1965; the two spacecraft moved around in close proximity for a little over five hours. After 206 orbits around Earth, Gemini 7 returned home on 18 December 1965.

Lovell's next trip to space was as commander of Gemini 12, the last flight of Project Gemini. He was accompanied by astronaut Buzz Aldrin, who completed three extravehicular activity operations during the mission.

The next step for Lovell was the Moon. Apollo 8 launched on 21 December 1968 with Borman as the commander, William Anders as the Lunar Module pilot and Lovell as the Command Module pilot. The trio successfully completed their trip around the Moon, marking the first time any human had journeyed so far from Earth and witnessed the far side of the Moon. The crew made six telecast appearances during their trip. Millions of people watched the astronauts deliver a Christmas address from space, in which they read passages from the Bible and described the view of space and Earth unfurling beneath them. Apollo 8 returned to Earth on 27 December 1968.

Lovell was Command Module pilot of Apollo 8, becoming one of the first to orbit the Moon alongside Borman and Anders

© NASA

Lovell's last mission was as commander of Apollo 13 in April 1970. He was joined by Lunar Module pilot Fred Haise and Command Module pilot Jack Swigert. Apollo 13 was the third targeted Moon landing. All appeared normal until the evening of 13 April, when the astronauts were just a day away from landing on the Moon. A stray spark ignited an oxygen tank within the Command Module, heavily damaging the spacecraft. The three men huddled in the undamaged Lunar Module – a spacecraft designed for two men to land on the Moon – for most of the next four days. To save energy, only the most essential systems were kept powered up. With the help of Mission Control, they arrived safely back on Earth on 17 April 1970.

Lovell retired from NASA and the Navy in 1973. He has received many awards and honours, including the Collier, Harmon and Goddard trophies, the Presidential Medal of Freedom, NASA Distinguished Service Medal and most recently the Congressional Space Medal of Honor.

All About Space

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